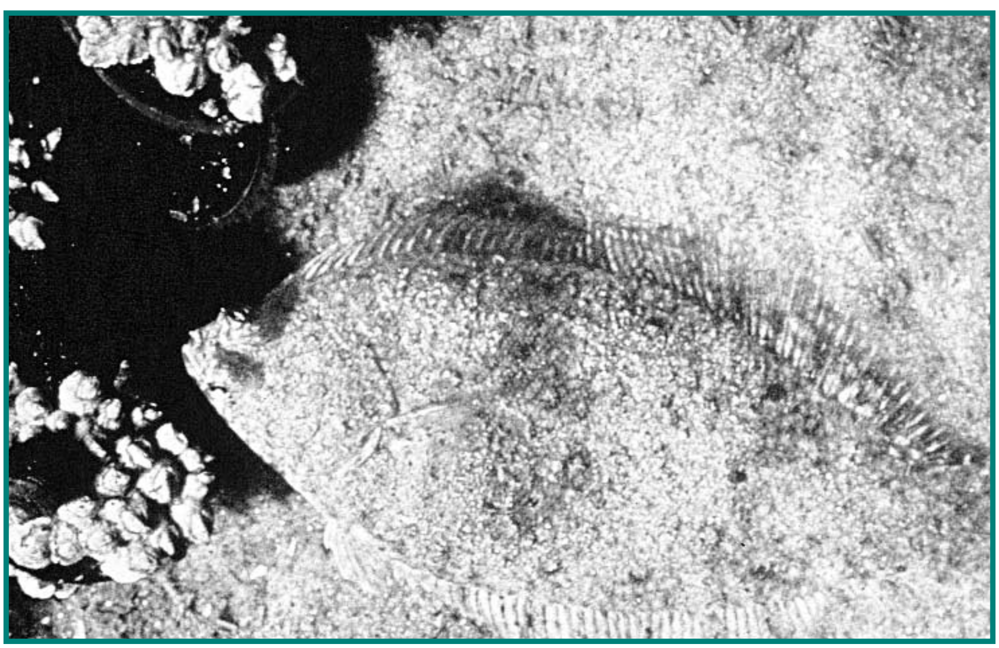
3 LIVING RESOURCES

The Great Bay and Hampton/Seabrook estuaries support a great diversity of plant and animal taxa including some rare and endangered species. The estuarine habitats that provide important functions to the seacoast are: shellfish beds, mud and sandflats, salt marshes, eelgrass beds, algal beds including rocky intertidal areas, barrier beach and dune systems, subtidal bottom with substrate ranging from mud to cobble and boulders, and tidal channels. Inventories of resident and migratory plant and animal species, information on habitats, communities biology and ecology can be found in a variety of previously published documents (Nelson, 1982; Short et al., 1992; NAI, 1977 and 1996; Sprankle, 1996; Banner and Hayes, 1996). The latter two studies provide excellent characterizations of important habitats for selected species. The selection of species discussed was based on a variety of criteria such as being listed as endangered or threatened, economic importance, inclusion by other significant inventories, etc. The approach used as the basis for the Banner and Hayes (1996) report was developed by the US Fish and Wildlife Service with the Gulf of Maine Council on the Marine Environment; a detailed description of their approach is provided in the report. The purpose of this chapter is to provide an up to date and comprehenisve description of New Hampshire's estuarine biota and to report on the status and trends of species and communities for which there is information. The communities and species described here were selected based on abundance, availability of information and on ecological and economic importance.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ESTUARINE INVERTEBRATES

Estuarine invertebrates consist of pelagic forms (zooplankton) as well as benthic (bottom dwelling) forms. The occurrence and distribution of species varies both temporally and spatially and are influenced by several factors including season, water depth, temperature, salinity, and for benthic forms, substratum type (i.e. mud/sand versus rock) is also a major factor.

3.1.1 ZOOPLANKTON

Zooplankton communities have been examined in the Great Bay Estuary by groups including Normandeau Associates, Inc. as part of the impact assessment for the Newington Generating Station (NAI, 1976), the University of New Hampshire (Turgeon, 1976), and in the Hampton/Seabrook Estuary (NAI, 1996) as part of the Seabrook Station Environmental Monitoring Program. Lists of zooplankton species for both estuarine areas can be found in Appendix I. In general, the zooplanktionic community can be partitioned into groups that exhibit three basic life history strategies. The holoplankton (e.g. copepods) are planktonic throughout their entire life cycle, while the meroplankton include the swimming larvae of species that are benthic as juveniles and adults (eg., bivalves, gastropods, decapod crustaceans). The tychoplankton include species such as mysids and harpactacoid copepods that alternate between a benthic and pelagic/planktonic existence.

The abundance and species composition of the zooplankton communities are temporally and spatially variable. Seasonally, their abundance increases throughout the spring, peaking in early summer and declining sharply in later summer. Spatially, the number of species decreases with distance from the open ocean. Data gathered by NAI (1976) in Great Bay indicate that holoplankton accounted for 73% of the taxa. The dominants holoplankton were copepod nauplii (29%), *Pseudocalanus minutus* (14%), *Oithona similis* (8%), tintinnid protozoans (7%) and *Temora longicornis* (2%). Meroplankton forms that only enter the zooplankton for reproduction comprised 22% of the zooplankton, including polychaete (11%), gastropod (5%), bivalve larvae (5%) and cirriped (barnacle) larvae (2%). Tychoplankton, primarily harpacticoid copepods which are only temporarily suspended in the plankton, represented 5% of zooplankton (NAI 1976).

Turgeon (1976) monitored meroplanktonic abundances within the Great Bay Estuary between 1970 and 1973. Bivalve larvae generally decreased from the mouth of the Estuary into Great Bay (Turgeon, 1976), and their numbers were greatest in July and September. Early stages of bivalve larvae occurred in the near-surface, while later stages occurred in deeper waters.

Barnacle nauplii (*Semibalanus balanoides*) are one of the first meroplankton forms to appear seasonally, during February, coinciding with the beginning of the spring phytoplankton bloom (Turgeon, 1976). Trochophores and early stage spionid polychaete larvae appear from April through May, having highest densities within the inner estuary (Turgeon, 1976). Mollusc larvae are most abundant during June through July with a second peak in abundance during September. Prosobranch veliger numbers were greatest during June and July being most abundant within Great Bay. Up to 25 veligers/l may occur within Great Bay, predominantly *Ilyanassa obsoleta* (Turgeon, 1976). These patterns were consistent during 1970-1973 (Turgeon, 1976), although absolute numbers varied from year to year.

Two distinct meroplanktonic communities were identified by Turgeon (1976), one predominating in the outer estuary and the second in Great Bay, with the two overlapping in the middle of the estuary. Larval populations were most dense and species composition most varied during February to July and September through November, e.g., the periods occurring between the winter minimum and summer maximum temperatures.

Larval abundances of soft-shell clam, *Mya arenaria*, are seasonally bimodal (Turgeon, 1976). Oyster larvae, as well as the larvae of several other bivalves, migrate vertically depending upon the tidal stage. Upward movement in the water column on flood tides and downward movement during ebbing tide promoted retention of larvae within Great Bay (Turgeon, 1976).

In the Hampton/Seabrook Estuary, zooplankton communities are similar to the Great Bay Estuary relative to temporal abundance patterns and dominance by the holoplanktonic copepods *Pseudocalanus sp.* and *Oithona sp.* (NAI, 1996). The meroplanktonic community is highly seasonal, with the greatest abundances occurring spring through fall. Dominant meroplanktonic species include the crustaceans *Balanus sp.* and *Carcinus meanas* and the bivalves *Hiatella sp., Anomia squamula* and *Mytilis edulis*. Little change in seasonal patterns and community composition has been observed in the past decade.

3.1.2 BENTHIC INVERTEBRATES

Benthic invertebrates include epibenthos such as motile bottom dwelling taxa (e.g snails, crabs and lobsters) and sessile taxa that attach to hard substrates (e.g. oysters, barnacles) as well as infaunal benthos that burrow in the sediments. Environmental conditions that are important in influencing invertebrate occurrence include water depth, substratum, temperature, salinity, etc. Of these, tidal regulated depth creates a division between intertidal and subtidal populations. Substratum type is a major determinant of species composition. Rock and shingle substrata are populated by epibenthic organisms, while mud and sand have both epibenthic and infaunal components.

Infaunal benthic populations can provide information that is integral to determining the ecological condition of estuaries. They are important regulators of the deposition and resuspension of bottom sediments and the exchange of constituents between bottom sediments and overlying water. Because of their burrowing and feeding habits, benthic animals affect the geochemical profiles of sediments and pore waters, particularly in higher salinity habitats with fine grained sediments. Extensive data bases on infaunal macrobenthos for most areas of the Great Bay Estuary have been compiled over the years. During a 1980-1981 monitoring program, 91 intertidal and 114 subtidal infaunal species were collected from 8 stations throughout the Great Bay Estuary (Nelson, 1981). A species list of Great Bay benthic infauna appears in Appendix E. Additional species lists, community analyses, temporal and spatial abundances can be found in NAI (1972-1980), Nelson (1982) and Webster (1991). More recent data (Armstrong, 1995; Johnston et al., 1994; Grizzle et al, manuscript in preparation; Langan, 1995, 1996) indicate that species richness and dominant species are essentially unchanged over the twenty plus year period (1972-1995). Grizzle et al. (manuscript in preparation) used three years of monthly data from four sites in the Great Bay Estuary to determine that throughout the year, biomass and the number of individuals can change dramatically, with peaks in both numbers and total biomass occurring in spring and fall. They attribute the low summer populations to predation. They also found, as did Nelson (1981), that community composition is determined to a great extent by sediment grain size. Although species dominance can vary spatially and temporally, generally speaking the dominant taxa in the Great Bay Estuary are the polychaetes *Streblospio benedicti*, *Heteromastus filiformis*, *Scolopos sp.*, *Pygospio elegans*, *Aricidea catherinae*, oligochaetes, the amphipod *Ampelisca abdita/vadorum*, and the bivalves *Gemma gemma* and *Macoma balthica*. Abundance, number of taxa and species diversity generally increase with decreasing distance from the open coast, indicating that fewer species are tolerant of the seasonal temperature extremes and daily tidal salinity changes, which can be as much as 18 ppt, in the upper reaches of Great Bay's tidal tributaries (Langan and Jones, 1996).

The species composition and abundance of benthic macrofaunal communities were examined at two sites in the Hampton/Seabrook Estuary from 1978-1995 to assess changes in the benthic community that could be attributed to the Seabrook Station's treatment plant discharge to Brown's River (NAI, 1996). Sampling was discontinued in May, 1995 due to the diversion of the treatment plant outfall to the offshore cooling water tunnel. Sample sites were located in the Brown's River and in Mill Creek. The dominant taxa at both sites included the polychaetes *Streblospio benedicti*, *Capitella capitata,* and *Hediste diversicolor* and oligiochaetes. Other common taxa included the polychaetes *Tharyx acutus* and *Spio setosa* and the soft shelled clam, *Mya arenaria*. These species are typical for East Coast estuarine areas with fine grained sediments (Watling, 1975) No significant differences in density, species composition or species diversity were found between sample sites or sample years for the study period. The data also indicated that the treatment plant outfall had little impact on the infaunal community in Brown's River. The clam worm, *Neanthes virens*, is also common in the intertidal areas of Hampton Harbor and supports a limited commercial bait industry.

Hardwick-Witman and Mathieson (1983) compared the epibenthic species composition of the rocky intertidal zone over a gradient extending from the mouth of the Piscataqua River into Great Bay. Within Great Bay, the dominant epibenthic intertidal invertebrates were *Ilyanassa obsoleta*, *Geukensia demissa*, *Crassostrea virginica*, *Balanus eberneus*, *Littorina littorea*, *L. saxatilis* and *L. obtusata*. Large beds of Eastern oysters, *Crassostrea virginica*, occur within Great Bay Estuary. This species, along with soft shelled clams, blue mussels and sea scallops will be discussed in more detail in a later section of this report. Other common epibenthic species in the Great Bay Estuary include horseshoe crabs (*Limulus polyphemus*), green crabs (*Carcinus meanas*), mud crabs (family Xanthidae), rock crabs (*Cancer irroratus*) and American lobsters (*Homarus americanus*).

The warm summer waters within Great Bay allow the persistence of several invertebrate species that are more common further south along the open Atlantic coast (Bousfield and Thomas, 1975). One example of such a disjunct warm-water taxon is the salt marsh amphipod *Gammarus palustris*; its northern distribution limits on the East Coast of the US are within Great Bay (Gable and Croker, 1977, 1978). Other examples of disjunct invertebrate species occurring within the Great Bay include *Balanus improvisus*, *Crassostrea virginica*, *Urosalpinx cinerea*, *Tellina agilis*, *Molgula manhattensis*, *Cliona* sp. and *Polydora* sp. (Turgeon, 1976). Such disjunct taxa may represent relict populations from a warmer period 10,000 to 6,000 yr B.P. (Bousfield and Thomas, 1975).

3.1.3 SELECTED INVERTEBRATE SPECIES

3.1.3.1 Molluscan Shellfish

The estuaries of New Hampshire are ideal habitat for a number of molluscan shellfish species. The Great Bay Estuary, including Little Harbor and the Back Channel area, supports populations of the eastern oyster (*Crassostrea virginica*), European flat or Belon oysters (*Ostrea edulis*), softshell clams (*Mya arenaria*), blue mussels (*Mytilus edulis*), razor clams (*Ensis directus*), and sea scallops (*Placopecten magellanicus*). Hampton Harbor supports populations of softshell clams and blue mussels. Molluscan shellfish are not only of economic importance for commercial and recreational harvesting, they are excellent bioindicators of estuarine condition because they are relatively long lived and integrate their environment over time. Additionally, because they are filter feeders, they play an important role in nutrient cycling, improving water clarity, and in removing significant quantities of nitrogen and phosphorus from the water column via phytoplankton and organic detritus consumption. Epibenthic shellfish such as mussels, oysters and scallops provide valuable habitat for a rich assemblage of invertebrates and fish while large infaunal bivalves oxygenate soft sediments with their burrowing activities. Oysters are considered by many estuarine ecologists to be a "keystone" species, and oyster beds in temperate estuaries are considered the equivalent of coral reefs in tropical seas. Many studies have shown that species density, diversity and biomass are significantly greater in oyster beds than on equivalent bottom without oysters. Molluscan shellfish play an important role in the ecology of estuaries and in the local and regional economies.

Eastern Oyster (Crassostrea virginica)

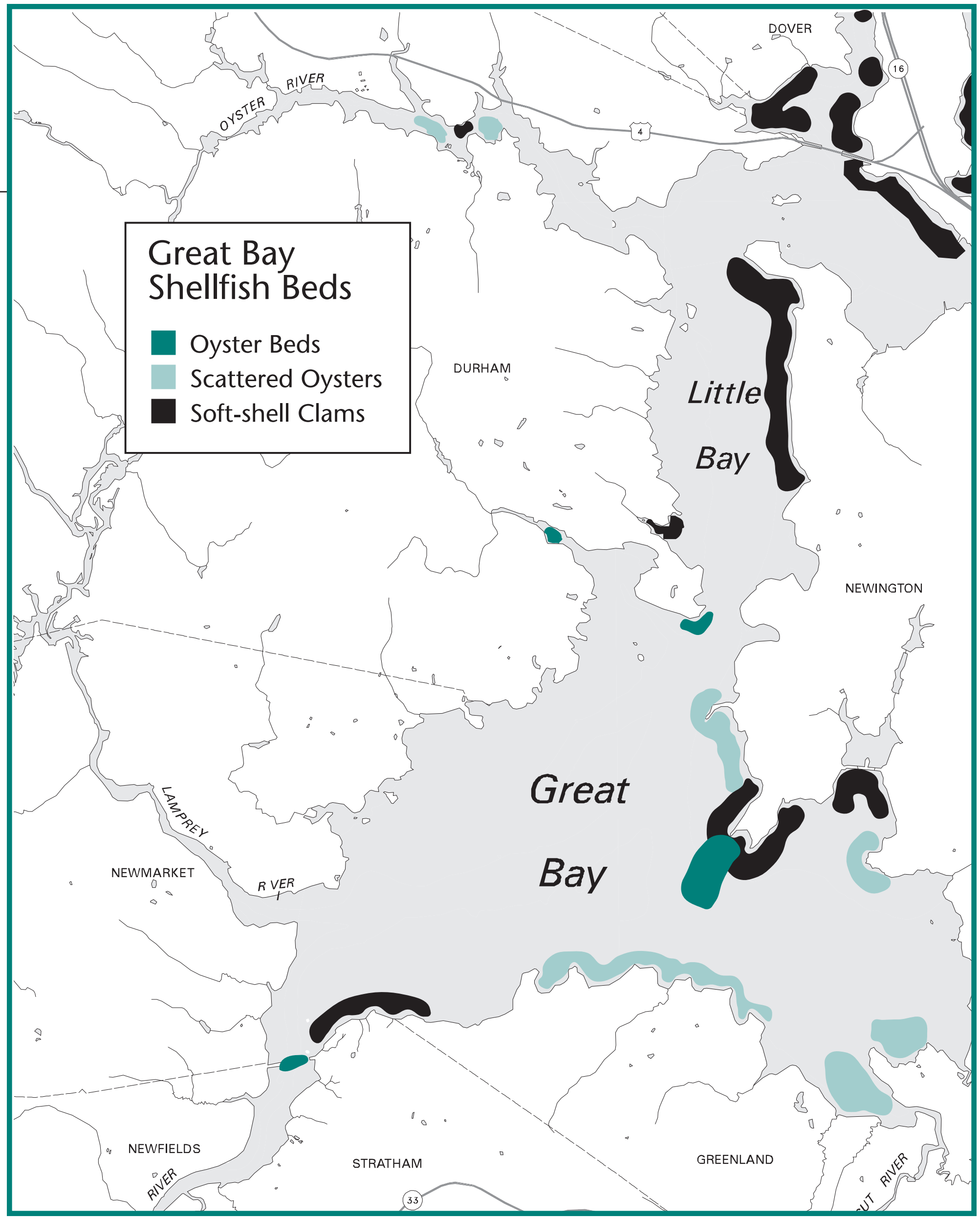
Eastern oysters range from the Gulf of Mexico to Atlantic Canada, though their occurrence is continuous only as far north as Cape Cod. North of Cape Cod, disjunct populations can be found in New Hampshire, Maine, the Canadian Maritimes and the province of Quebec. They are primarily an intertidal and shallow subtidal species and are most abundant in estuarine areas with firm substrates. Ice scouring in more northern regions limits their occurrence to shallow subtidal areas. Eastern oysters can tolerate salinities ranging from 2-3 ppt to full seawater salinity (34 ppt) though reproduction is depressed at low salinities. They can also tolerate temperatures ranging from -2°C to >30°C, however, feeding ceases and respiration is greatly depressed below 5°C. Unlike some bivalve species such as bay and sea scallops, they thrive in areas of high turbidity. Spawning occurs when water temperatures reach approximately 20°C, though in the more northern portion of their range, annual spawning may not always occur. The planktonic larvae remain in the water column for 14-20 days and settle on hard substrate, with a noticeable preference for the shells of their own species. Accounts of early European settlers reported that oysters were very abundant in the Great Bay Estuary, and shell middens indicate that oysters were consumed by native Americans. Though once harvested commercially, they now support a popular recreational fishery in New Hampshire.

The location and dimension of oyster beds in the Great Bay Estuary has been discussed in a number of publications dating back to the late 1940's. The present beds are shown in Figure 3.1. Maps of oyster bed locations can be found in Ayer et al. (1970), Nelson (1981) and Sale et al. (1992). Oyster habitat based on occurrence and suitability modeling has been recently mapped by the U.S. Fish and Wildlife (Banner and Hayes, 1996). A map depicting the location of these beds in 1980 is shown in Figure 1.5. Jackson (1944) gave a general description of the locations of oyster beds, and described reduction in oyster populations due to siltation and pollution. He recommended rejuvenation of the oyster beds through shell planting and cultivation and suggested that Great Bay oysters could become of considerable commercial importance. Though numbers for acreage and density from that period are not reported, it is obvious from Jackson's description that even in the 1940's, much of the oyster habitat in the Great Bay Estuary had already been lost. Ayer et al (1970) described the location, acreage and population structure of Great Bay oysters and estimated a standing crop of market sized oysters of 38,000 bushels. This estimate was calculated using the areal coverage of the all beds and density and size frequency of oysters in the Oyster River only, assuming equal density and size structure for all beds. Ayer et al. (1970) also studied spatfall and growth in various locations and explored the possibility of a seed oyster industry in New Hampshire. Spatfall was highly variable both spatially and temporally. He also found that although all bivalve shell caught spat, oyster shell produced the best results. Additionally, he recommended the use of hatchery reared larvae for seed production as a means of producing marketable oysters in a shorter period of time.

Nelson (1982) estimated the density and standing crop of market-sized oys-

FIGURE 3.1

Shellfish resources in Great Bay, Little Bay and tributaries.



ters, and NH F&G conducted additional estimates on selected beds in 1991 and 1993. These data are presented in Table 3.1. It is very difficult to determine change over time from these data. The 1970 estimate only calculated standing crop/acre for the Oyster River bed and applied this density to a total of 50 acres in the estuary, though the number of acres for each bed were not defined. The Adams Point bed, one of the most popular harvest spots in Great Bay, is not included in the 1981 estimate, but appears in 1991 and 1993. The 1981 data reports a great abundance of oysters in southwest Great Bay, a 90% reduction from 1981 to 1991, and no mention of this bed in 1993. More recent survey work (1996-1997) has failed to locate a large concentration of oysters in the southwest portion of Great Bay, though a small concentration can be found in the vicinity of the railroad bridge that crosses the Squamscott River. Reduction in areal coverage of some beds is indicated by the data from for the Bellamy and Oyster river beds from 1991 to 1993, with a 67% reduction in the Bellamy River and a 19% reduction in the Oyster River. Jackson (1944) also mentions a significant reduction in the size of Oyster River bed, though precise changes in dimension are not reported. Density data for all sizes of oysters were obtained for

Acreage and standing crop of adult oysters in the Great Bay Estuary. **TABLE 3.1**

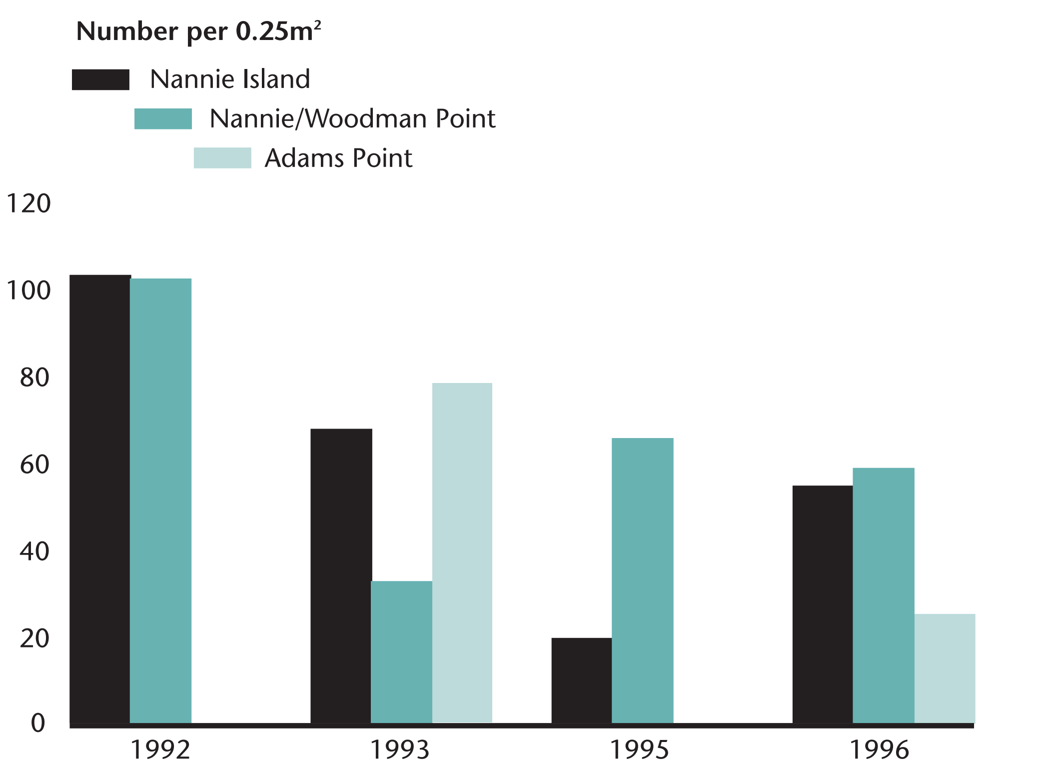
Location	1970 acres	1970 bushels	1981 acres	1981 bushels	1991 acres	1991 bushels	1993 acres	1993 bushels
Nannie Island	?	?	18.5	18193	?	?	18.5	20,615
Adams Point	?	?	?	?	?	?	5.1	8,358
Oyster River	7.4	5594	7.4	12,062	7.4	3,369	6	10,038
Southwest Great Bay	?	?	9.8	59,122	9.8	6,389	?	?
Bellamy River	?	?	3.1	3,891	3.1	6,865	1	1,074
Piscataqua River	?	?	12.3	23,735	12.3	13,135	12.3	5,412
Total Estimated	50	37,800	51.1	117,003	NA			45,497

the years 1991, 1993, 1995 and 1996 for two beds near Nannie Island and for 1993 and 1996 for Adams Point by personnel from the NH Fish and Game. These data are illustrated in Figure 3.2. According to the data, from 1991 to 1996, there has been a 46% reduction in the Nannie Island south bed, a 42% reduction in the Nannie Island/Woodman Point bed and a 69% reduction in the Adams Point bed.

These data suggest a decline in oyster populations in Great Bay. With the exception of the 1970 data, however, all these estimates are based on a relatively small number of samples and should be considered rough estimates at best. More recent studies provide improved information on oyster resources (Langan, 1997) and harvest (NHF&G, 1997c).

It is also useful to examine other sources of information when trying to determine trends in oyster populations. A survey of recreational harvesters conducted by Manalo et al (1991) asked the recreational license holders for an esti-

Density of oyster beds in Great Bay: 1991-1996. **FIGURE 3.2**



mate of the amount of time it took to harvest one bushel of oysters prior to and after 1989. Seventy four percent of the respondents indicated that it took them longer to harvest their limit after 1989. A more recent survey in 1997 by NHF&G asked recreational harvesters their opinion about the general abundance of oysters in Great Bay. Fifty five percent expressed the opinion that the abundance was lower than in prior years, six percent thought is was higher, eighteen percent reported no change and seventeen percent didn't know. A commercial oyster harvester on the Maine side of the Piscataqua River ceased harvesting operations in 1995 after an epizootic of MSX caused mass mortalities of oysters in the Salmon Falls and Piscataqua rivers. Spinney Creek Shellfish, Inc. estimated 90% mortality in the Salmon Falls River beds, and 50-70% mortality in the Piscataqua River beds (T. Howell, personal communication). Data collected in the Salmon Falls and upper Piscataqua rivers in 1997 support these mortality estimates (Langan, unpublished data). Though systemic MSX infections in the Oyster River and Great Bay were lower, there is strong evidence, in the form of hinged or "boxed" oysters, to suspect that considerable disease related mortalities occurred in all areas of the Great Bay Estuary. More recent studies report the presence of MSX and dermo to be throughout the estuary (NHF&G, 1999).

As stated in another section of this report, larval recruitment and juvenile survival are important factors in maintaining oyster populations. Ayer et al. (1970) indicated that spat settlement in Great Bay was highly variable both spatially and temporally. They also reported that the percent of adult oysters spawning varies from year to year. Data collected by the Jackson Estuarine Laboratory from 1991 through 1996 indicates that light sets occurred in 1991, 1992 and 1996, a heavy set occurred in 1993 and virtually no set occurred in 1994 and 1995 (Dr. R. Langan, unpublished). The reasons for poor sets may be related to meteorological (temperature and salinity) and biological (sufficient food for adults and larvae, disease) conditions, but may also be related to the amount of available substrate for larval attachment. MacKenzie (1989) reported that the primary limiting factor in determining oyster recruitment is the amount of clean, hard substrate for larval attachment. With this in mind, it is interesting to note that the 1997 oyster harvester survey conducted by the Fish and Game found that only 27% of recreational harvesters return shell to the oyster beds. This would certainly support the concept that lack of available substrate for larval settlement is contributing to the poor spat settlement and juvenile recruitment. Though the lack of consistency in data collection makes it very difficult to be scientifically certain, it appears that oyster populations in the Great Bay Estuary have declined in recent years due to a combination of inconsistent recruitment and disease.

A long-term trend in oyster populations in the Great Bay Estuary is also difficult to determine since there is a lack of historical data. The report by Jackson (1944) certainly indicates that by the mid-twentieth century, oysters populations had declined significantly due to overharvesting, pollution and siltation. Though these conditions have improved greatly in recent years, it is unlikely that oyster populations have increased much since the 1940's. We may never know the original baseline of oyster abundance, however, it is probably safe to say that oyster populations in the Great Bay Estuary are a fraction of what they once were.

Diseases of the Eastern Oyster in New Hampshire

The oyster diseases MSX and Dermo, caused by the protozoan parasites *Haplosporidium nelsoni* and *Perkinsus marinus,* respectively, have recently been detected in oysters from the Great Bay Estuary. These diseases were once thought to be limited in their range by temperature and salinity to the mid-Atlantic region of the U.S., however their occurrence has expanded in recent years through New England and the disease organisms have been identified as far

Prevalence, systemic infection and MSX mortalities of oysters in the Great Bay Estuary, 1995. **TABLE 3.2**

Location	**Date**	**Mean Shell Height (mm)**	**Prevalence %**	**Systemic Infections %**	**Dead %**
Salmon Falls	10/27/95	81	81	50	83
Piscataqua (Power Lines)	10/27/95	74	70	25	64
Piscataqua (Sturgeon Creek)	10/27/95	75	65	40	42
Piscataqua (Stacy Creek)	10/27/95	77	45	10	25
Oyster River	12/18/95	103	50	30	NA
Adams Point	11/06/95	95	40	15	NA
Nannie Island	11/06/95	96	15	5	NA

north as the Damariscotta River in Maine. These diseases have had a major impact on oyster populations in the Gulf of Mexico (Dermo) and have crippled the oyster industries in Delaware and Chesapeake Bays (MSX and Dermo). Both diseases become more virulent during dry periods in the summer, when high temperature and salinity conditions persist. The method of transmission of MSX is unknown, though it is suspected that an intermediate host for the infectious life stage may be involved. Dermo can be transmitted directly from one oyster to another as well as by a wide variety of organisms included many bivalve species, though it appears to be infectious only to Eastern oysters

The first recorded MSX epizootic caused by the oyster parasite *Haplosporidium nelsoni* occurred in 1995 in the Great Bay Estuary (Barber et al., 1997), even though the parasite was identified in Piscataqua River oysters in 1983 (Sherburne and Bean, 1991) and again in 1994 (B. Barber, unpublished data). Unusual mortalities were observed in the Piscataqua River by Maine harvesters in August, 1995, and samples were examined for the *H. nelsoni* parasite. Samples of adult oysters (74-102 mm) were examined from beds in the Salmon Falls River, three sites in the Piscataqua River, the Oyster River, Adams Point and Nannie Island. The disease prevalence, percent of systemic infections and % dead from the disease are shown in Table 3.2. The disease caused the greatest mortalities in the Salmon Falls River and farthest upstream beds in the Piscataqua River, with lower prevalence and % systemic infections with increasing distance from the Piscataqua River. An examination of the climatological data, water temperature and salinity indicates that the conditions in 1995 were favorable for an MSX epizootic. Both temperature and salinity increased in all areas of the estuary from 1993 - 1995 due to drought conditions. The disease caused mortalities in all oyster beds and significant mortalities in some, and has had an impact on oyster populations that has not been fully assessed. Oyster samples from Nannie Island and Fox Point were analyzed in April, 1996. A 10% prevalence and no systemic infections were found. Samples of April, 1997, broodstock oysters from Fox Point were examined and a 17% prevalence of light infections was found. Observations of gaping and recently dead oysters from Nannie Island and Adams Point in the spring of 1997 (R. Langan, personal observation) indicates the possibility of continued mortalities from the disease despite the lower than average salinities in 1996 and the first half of 1997. A regular program of monitoring for *H. nelsoni* and *P. marinus* is underway (NHF&G, 1999).

The protozoan oyster parasite *Perkinsus marinus*, the causative agent of the Dermo disease, was identified in oysters from Spinney Creek, Maine in September, 1996. A large percentage of the oysters were infected, and some had heavy infections. No mortalities were attributed to the disease at that time. Additional samples were obtained in

December, 1997, from two sites in the Piscataqua River and Nannie Island in Great Bay. A "dermo-like" body was found in one of 25 oysters from Nannie Island, and 2 of 25 oysters from at Sturgeon Creek. A heavy infection was found in one of 25 oysters near the "three rivers" point in the Piscataqua River. No infected oysters were found (out of 25) at Seal Rock in the Piscataqua River. Thirty oysters from Fox Point were examined in March, 1997 and no infected oysters were found. Additional diagnostics have been conducted in the summer and fall of 1997. A low prevalence of light Dermo infections have been found in oysters from Adams Point, Nannie Island, and the Oyster River, while a higher prevalence and one oyster with advanced infection was found in the Piscataqua River. A neoplasia-like body was seen also by tissue examinations.

Belon or European Flat Oyster *(Ostrea edulis)*

The Belon oyster, native to Western Europe and the British Isles, was introduced into the Great Bay Estuary in the late 1970's by two commercial companies as an aquaculture species, and was grown in suspension culture in Little Bay, the Piscataqua River and Little Harbor, and in bottom culture in Spinney Creek. The Belon oyster prefers lower temperatures and higher salinities than the indigenous eastern oyster, and therefore habitat overlap is unlikely. Though similar in many respects to the Eastern oyster, *O. edulis* broods fertilized eggs internally, and releases larvae at the trochophore stage. Spinney Creek, where there is still active aquaculture of this species, has a spawning adult population capable of producing large natural sets of oysters, though few juveniles survive in Spinney Creek due to unfavorable temperatures in late summer. "Escapees" of this species have established natural, reproductive populations in the Piscataqua River, Portsmouth Harbor, Little Harbor, Rye Harbor, areas of the Back Bay in Portsmouth and more recently in Gosport Harbor at the Isles of Shoals. Though the actual numbers of this species is unknown, the fact that conditions are favorable for maintaining natural populations is interesting from a perspective of commercial aquaculture, since this species is highly valued and in great demand.

Softshell Clams *(Mya arenaria)*

Softshell clams are an infaunal bivalve that range from the mid-Atlantic region of the U.S. through the Canadian Maritimes. They can be found in substrates ranging from gravel to very soft mud, but appear to be most abundant in muddy or silty sand. Adults may burrow as deep as 20 cm into the substrate. They inhabit the intertidal and shallow subtidal areas of estuaries and coastal bays, and can tolerate a wide range of temperature and salinity. Though usually not a numerically dominant member of the infaunal community, in areas of high abundance they can represent a very large fraction of the infaunal biomass. Spawning occurs during two periods, spring and late summer-fall, though the greatest larval densities and greatest spat settlement occurs during the later spawning period. The larvae are planktonic for approximately 21 days. This species was also harvested commercially up to the mid 20th century, and is now the most popular recreational shellfish species in New Hampshire.

There is a great deal of uncertainty regarding abundances of softshell clams in the Great Bay Estuary. The locations of clam beds were reported by Nelson (1981) (Figure 3.1) and clam habitat, based primarily on suitability indices was recently mapped by the U.S. Fish and Wildlife (Banner and Hayes, 1996). Though clams can be found in most intertidal flats, densities are generally sparse and are spatially and temporally variable. There is some amount of recreational clamming in Great Bay, however, if a clammer were asked for his or her preferred location in New Hampshire, they would undoubtedly choose Hampton Harbor. Jackson (1944) reported acreage of flats in the Great Bay and the NH Fish and Game reported the location and abundance of clams in Great Bay (Nelson, 1981), Though seed clams were abundant at most sites, it appears that few survive since the abundance of larger size classes was low at all sites. The abundance of seed clams may have also been the result of a particularly heavy set that year. NH Fish and Game (1991) also reported acreage and standing crop of clams in the Great Bay Estuary in 1991. These data are presented in Table 3.3. A recent study provided more recent data on clam populations in the Great Bay Estuary (Langan, 1999). Results show moderate to high density of clams on the western flats of the Salmon Falls River and near Sandy Point in Great Bay, and low density on the eastern shore of lower Little Bay and along southern shoreline of Dover Point in Little Bay.

Jones and Langan (1996c) estimated clam abundance and spatfall on several flats in the Little Harbor area. They found that densities were generally low, despite the presence of suitable habitat, and that recent spatfall was poor. These data are presented in Table 3.4 and the locations of shellfish resources are shown in Figure 3.3. NH Fish and Game (1991) reported that there were 400 acres of clam flats in Little Harbor, the Back Channel area and in Sagamore Creek and a standing stock of 1,600 bushels of adult clams. A more recent report provides an updated database on clam populations in Back Channel (Langan et al., 1999b).

There is currently insufficient data to establish any trends in clam populations in Great Bay or Little Harbor. For a historical perspective, the report by Jackson (1944) stated that clams declined steadily in number between 1900 and 1944, and at that time there was "only a vestige of their former abundance," though no quantitative

Softshell clam flat acreage and abundance in Great Bay Estuary. **TABLE 3.3**

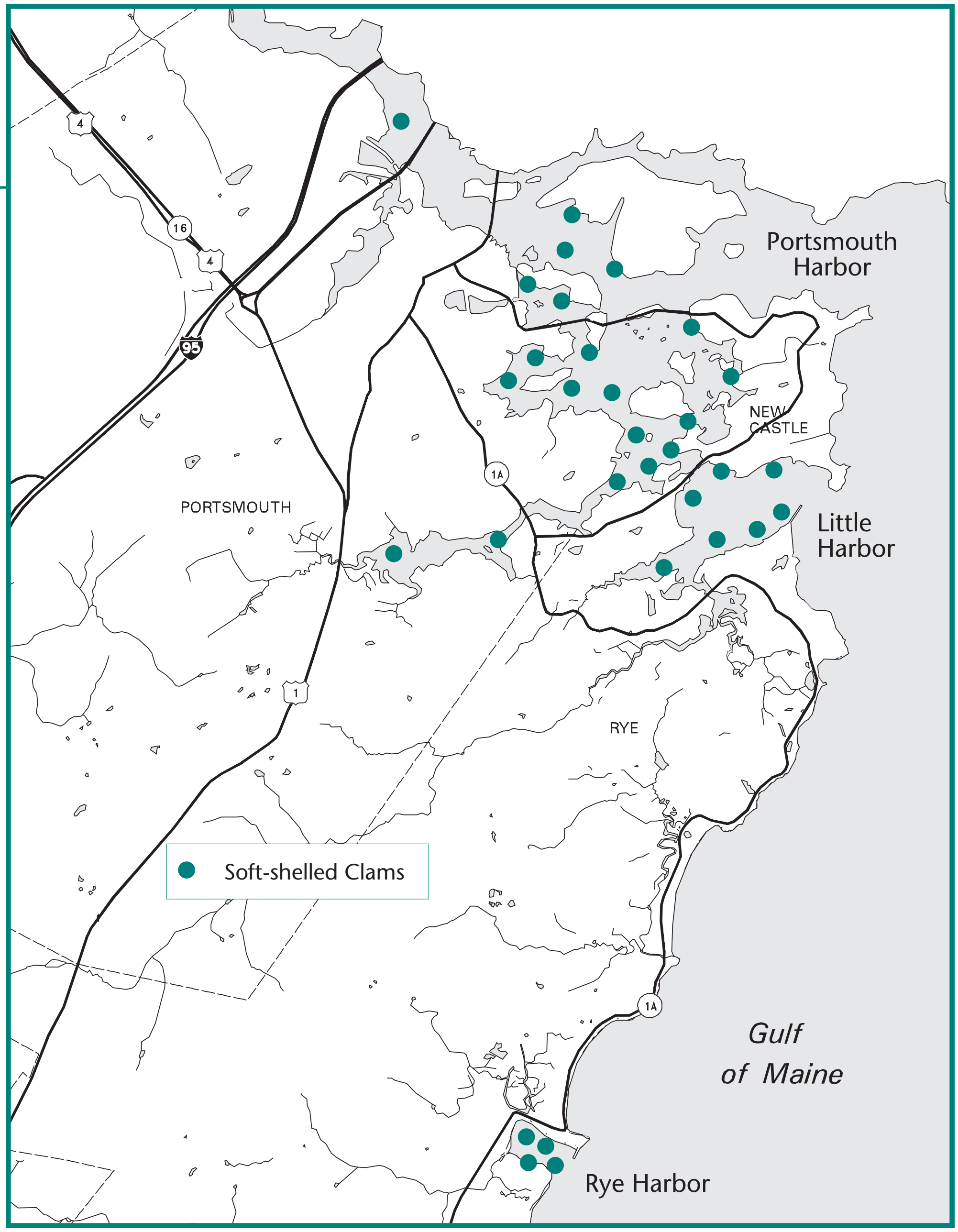
Location	Jackson (1944) Acreage	NH F&G (1991) Acreage	NH F&G (1991) Total Bushels
Salmon Falls River	125	125	500
Cocheco River	140	140	560
Piscataqua River	265	265	1060
Bellamy River	300	300	1200
Oyster River	225	225	900
Lamprey River	60	60	240
Squamscott River	180	180	720
Little Bay	430	380	1520
Great Bay	1000	500	2000
Total	2725	2175	8700

Softshell clam flat density and abundance in Little Harbor. **TABLE 3.4**

Clamflat No.	**Location**	**Acres**	**Density** #/m²	**Total Area** m²	**Abundance**	**# Bushels** 1200 clams/bu
1	Odiorne: West	0.4	1.6	1,618	2,589	2
2	Odiorne: East	8.6	4.4	34,796	153,102	18
3	Witch Creek: *Unsuitable substrate*					
4	Triangle	3.2	12:53	12,950	162,264	135
5	Wentworth	12.1	2.02	48,968	98,915	82
6	Seavey	6.4	5.07	25,900	131,313	1 09
7	Berrys Brook	4.2	4.65	18,817	87,499	73
Total		34.9	5.0	143,049	635,682	530

FIGURE 3.3

Shellfish resources in Portsmouth, Rye, and Little Harbors.



data are available for that period.

The locations of clam resources in Hampton Harbor are illustrated in Figure 3.4. Abundance and age composition of clams from the Hampton River Confluence, Common Island and Seabrook (middle ground) clam flats in Hampton Harbor have been monitored since 1974 by Normandeau Associates for the Public Service Company of New Hampshire as a requirement of their license to operate the Seabrook nuclear power plant. Larval abundance has been monitored for the same time period at a nearfield station outside the Harbor. This is without a doubt the most complete dataset for shellfish in New Hampshire and the long term data are presented in detail in the utilities' 1996 environmental report (NAI, 1996). Since only a summary of the information is presented here, the reader is referred to the referenced document for more detail.

Larval Abundance

Mya larvae are present in the water column from May through October and maximum densities are typically recorded in late summer or early fall with a secondary peak in early summer. This timing of the peak density can vary in timing and magnitude. Larval density has

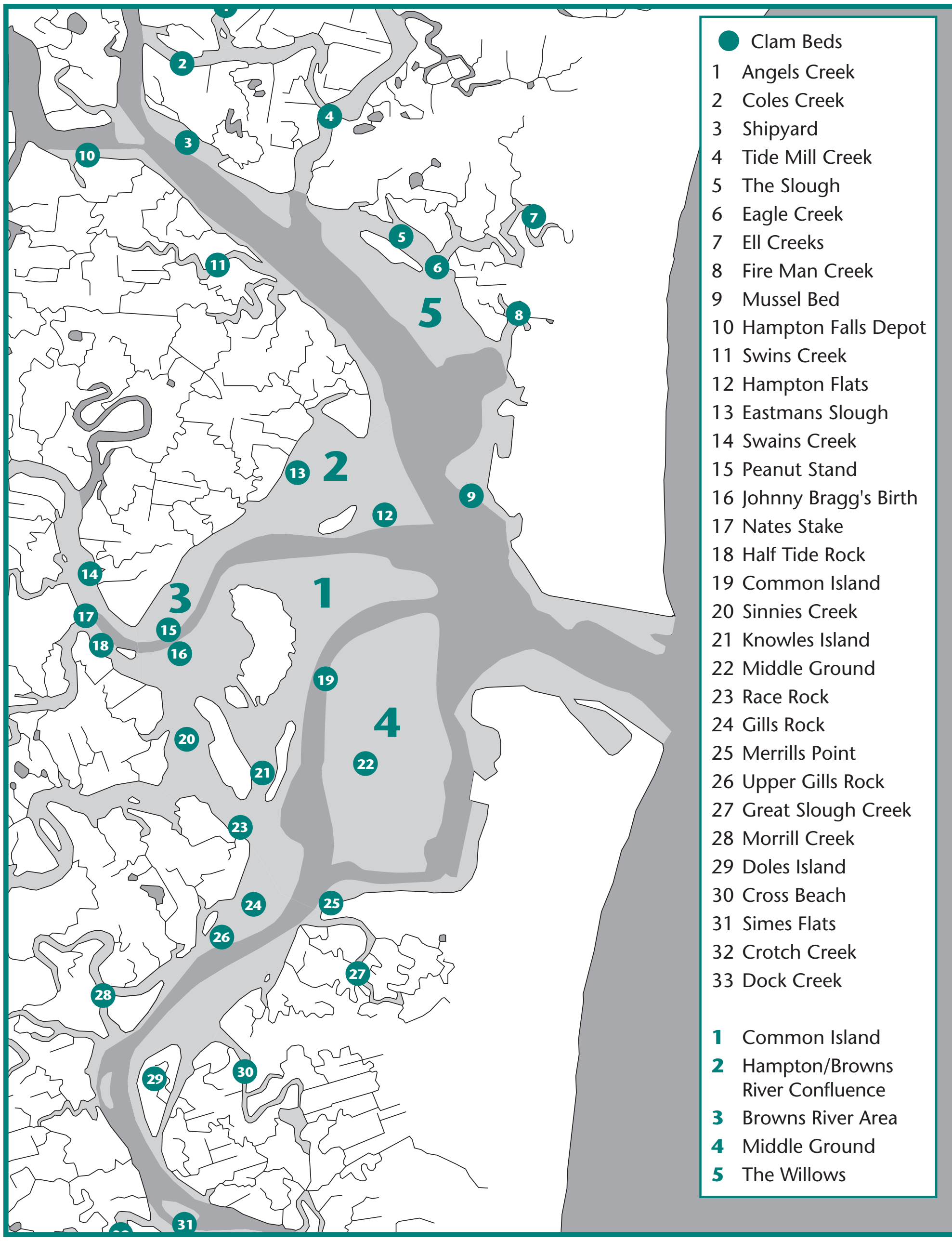


FIGURE 3.4

Shellfish resources in the Hampton Harbor Estuary.

been generally lower in the years 1991-1995 than in the period from 1978-1981. Gonadal studies indicate that spawning in Hampton Harbor usually follows the appearance of larvae at offshore stations, indicating that the early larvae are not produced by local broodstock. Based on the current patterns in the area, it is likely that recruitment of larvae of non-local origin occurs.

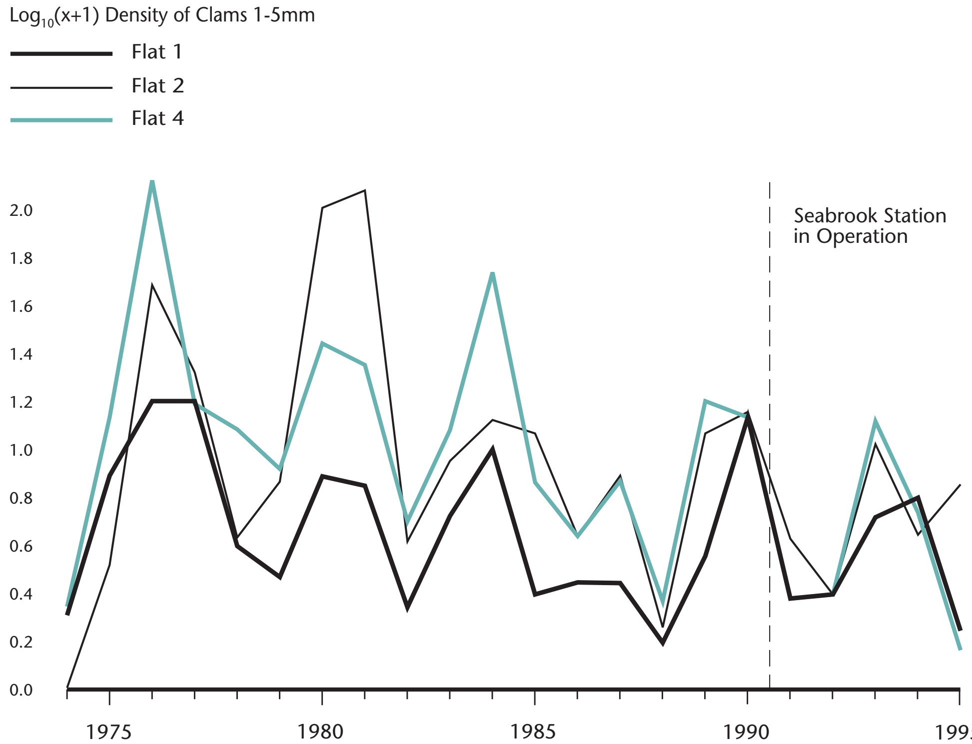
Young of the Year

Young of the year (YOY) clams are newly settled spat ranging from 1-5 mm. Historically YOY clam density has been highly variable both spatially and temporally in Hampton Harbor. In 1995, YOY density on the Seabrook Flat was lower than all years since 1974, while on the Hampton River confluence flat, density was higher than 1991-1994, but lower than the 1974-1989 average. Density was the second lowest since 1974 on the Common Island flat. Long term density appears to have declined slightly since 1974, and good sets appear to occur approximately every three to four years (Figure 3.5).

Spat

Density of spat (6-25 mm), or year one clams that have successfully overwin-

FIGURE 3.5 *Annual mean log10(x+1) density (number per ft2) of clams 1-5 mm length: 1974-1995. Data from NAI (1995)*



tered, has been variable for the study period, however, it can be stated that density on all flats was highest from 1977 through 1981, lowest from 1981 through 1989, and although much lower than the 1977-81 abundances, peaks in density occurred in 1990 and 1994. These peaks in density correspond well to the YOY densities except for the years from 1983 through 1987 where it appears that reasonably good sets did not survive the winter (Figure 3.6).

Juveniles

Juvenile clams (26-50 mm), are more than likely two year old clams. The annual density of juveniles corresponds well with spat density with a one year lag time. Clams of this size were most abundant from 1979-1981, and have declined steadily since, though smaller peak densities were recorded in 1990 and 1995 (Figure 3.7).

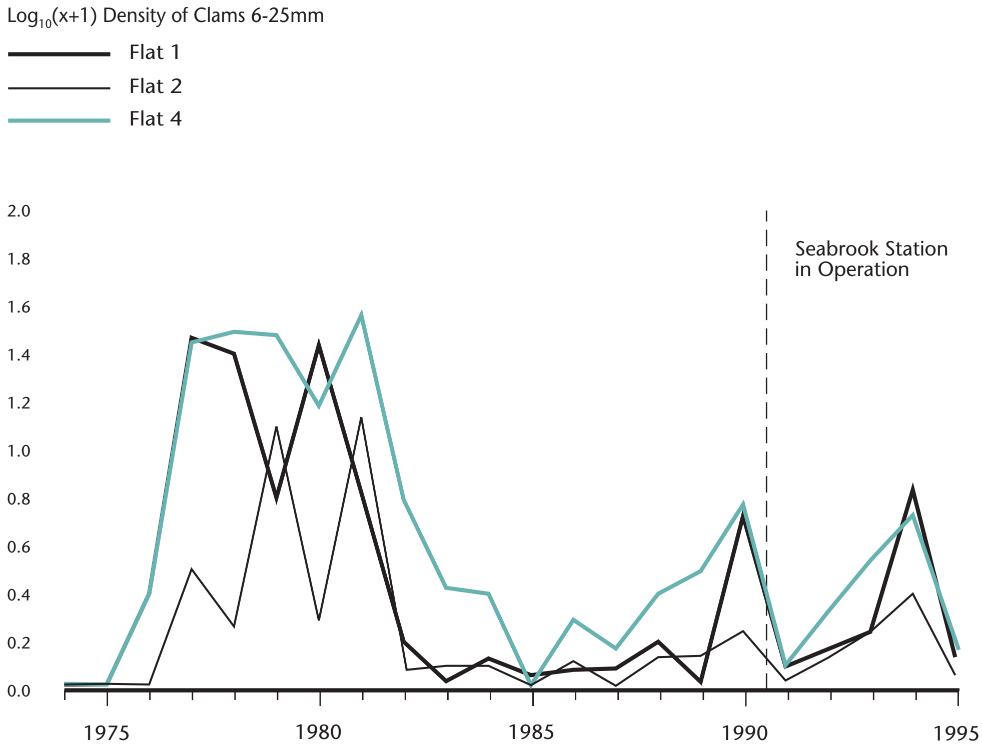
Adults

Adult clams (>50 mm) were abundant in 1971 through 1975 (Savage and Dunlop 1983), declined from 1976-1979, and reached peak abundances from 1980-1984. The steady sharp decline in abundance beginning in 1984 was very likely due to heavy harvest pressure. A classic predator prey relationship, where the change in density of prey is tracked by a change in predator density (with some lag period), exists between the clam population and the number of adult clam licenses sold (Figure 3.8). Closure of the flats in 1989 resulted in minor recovery of adult clam density on the Common Island flat from 1989 to 1995, a much greater increase in density in clams on the Seabrook flat, and little change on the Hampton River confluence flat, though an increase was recorded from 1994-1995. The Common Island flat was reopened in 1994, however the effects of recreational clamming in 1994 and 1995 appeared to have little effect on clam density (Figure 3.9). A recent study focused on removing blue mussels from flats to improve clam habitats (Langan and Barnaby, 1998).

Predation, particularly of small clams, can greatly affect the survival of clams to harvestable size. The green

Annual mean log10(x+1) density (number per ft2) of clams 6-25 mm length: 1974-1995. Data from NAI (1995).

FIGURE 3.6



Annual mean log10(x+1) density (number per ft2) of clams 26-50 mm length: 1974-1995. Data from NAI (1995).

FIGURE 3.7

FIGURE 3.8 *Number of clam licenses and the adult clam standing crop (bushels) in Hampton-Seabrook Harbor: 1971-1987. Data from NAI (1995).*

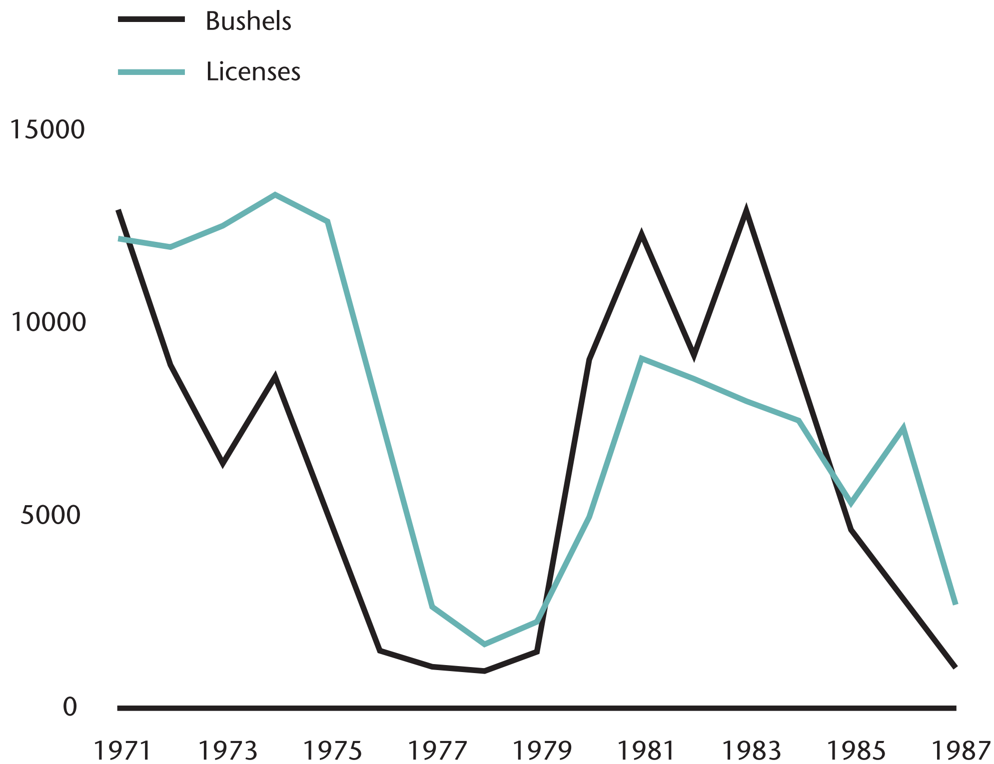
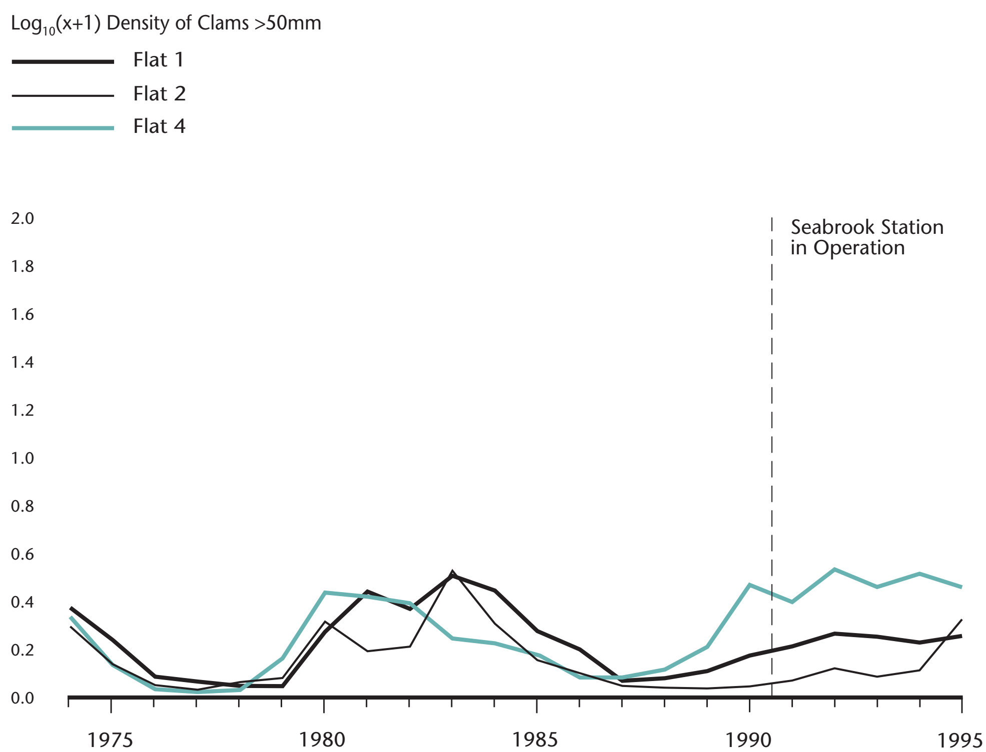


FIGURE 3.9 *Annual mean log10(x+1) density (number per ft2) of clams >50 mm length: 1974-1995. Data from NAI (1995).*



crab, a major predator of *Mya*, has been highly variable over time in Hampton Harbor, but unlike human predators, their numbers are influenced by minimum winter water temperatures rather than prey (clam) abundance. Even in years of low crab abundance, there appears to be sufficient numbers of crabs in the Harbor to impact juvenile clam abundance. Other predators include nematodes, horseshoe crabs and birds. Though massive sets of clams could "breakthrough" and overwhelm predation pressure, it is unlikely that this will happen without substantial natural or artificial reseeding and predator protection (Savage and Dunlop, 1983).

Ultimately, it appears that the controlling factors determining clam populations in Hampton Harbor are larval settlement, predation, prevalence of sarcomatous neoplasia (Hampton River flat) and harvest pressure. Savage and Dunlop (1983) stated that unless and seed clams are protected from predators and harvest pressure on adult clams is controlled, it would be very difficult for even large sets of clams to overcome the rate of predation and produce increased quantities of adult clams.

Softshell Clam Diseases: Sarcomatous neoplasia

Sarcomatous neoplasia, a lethal form of leukemia in clams, has the potential to cause serious mortalities in the softshell clams. The infection has been observed in relatively pristine waters, however it is suspected that the rate of infection is enhanced by pollution.

Sarcomatous neoplasia was observed in Hampton Harbor clam populations in October, 1986 and February, 1987 from the Common Island (6%) and Hampton River confluence (27%) flats (NAI, 1996). No infections were found on the Seabrook flat (middle ground). Clam surveys in 1987 indicated that juvenile and adult densities were reduced by 50% in the two flats where disease was identified, while the population was unchanged on the middle ground. It is suspected that the reduced densities resulted from disease related mortalities. In November, 1989, twelve of fifteen clams (80%) from the Hampton River were infected. From 1990-1995, adult clam densities quadrupled in the middle ground, while Common Island densities did not change, and Hampton River density decreased by 50%. It is suspected that disease may have contributed to the observed reductions. Clams in the Great Bay Estuary have not been examined for neoplasia.

Blue Mussels *(Mytilis edulis)*

The blue mussel is widely distributed in the North Atlantic and occurs in Europe as well as North America. On the East Coast of the U.S., it ranges from Cape Hatteras to the Arctic Circle. Mussels inhabit the intertidal and subtidal zones of estuaries and the open coast. Though primarily a shallow water species, they are sometimes found at considerable depths. They can tolerate temperatures ranging from -2°C to 25°C and salinities ranging from 5 ppt to 35 ppt, though prolonged expose to salinities below 15 ppt are lethal. Spawning can occur year round, though the peak spawning period is June through August. Like other bivalves, the larvae are planktonic and remain in the water column for three to five weeks. Initial settlement occurs in shallow water on any firm substrate, however, newly attached juvenile mussels can detach their byssal threads and drift with the currents in search of other suitable attachment surfaces. Though mussels are harvested in large quantities and are an important aquaculture species in Europe, Canada and other parts of the world, they are largely ignored as a food species in New England. They are considered by many to be a nuisance species since colonization leads to fouling of industrial and coastal structures, as well as the hulls of ships.

Blue mussels can be found in the Great Bay Estuary attached to any hard substrate in the intertidal and subtidal zones, and also colonize intertidal flats in scattered clumps and contiguous mats. Though during high salinity periods mussels may be found in most areas of the estuary, their limited tolerance for low salinity limits their permanent upstream distribution to the area around Dover Point. Mussels are most abundant in the lower Piscataqua River, Portsmouth Harbor and Little Harbor. The location of some mussel beds in the lower estuary was identified as part of the Ecological Risk Assessment study for the Portsmouth Naval Shipyard. Density, size and condition index of mussels from a number of sites was measured for this study (Johnston et al., 1994). Banner and Hayes (1996) mapped blue mussel habitat using a suitability index model, however, the lower estuary where mussels are most abundant was not included in their study.

Long term records of larval abundance and juvenile settlement of blue mussels have been maintained as part of the PSNH environmental studies program by Normandeau Associates (NAI, 1996). Mussel larvae are a dominant taxon in the nearshore plankton community and are the dominant noncolonial taxon on shallow depth fouling panels. Density of larvae has increased in recent years, and though settlement varies annually, in general it has increased in recent years as well. Mussels can be found in the estuary attached to hard substrate in both the intertidal and subtidal zones, and can form extensive beds on tidal flats. Banner and Hayes (1996) have mapped mussel habitat using occurrence and suitability indices. The most prominent beds are located in the Hampton River, Blackwater River, and on the Seabrook middle ground clam flat. There is no scientifically documented change in abundance, though there is information (P. Tilton, personal communication) that the coverage of mussels on the Seabrook flat has increased in recent years. Mussel density on the flats in Seabrook can be as high as 3500/m^2 (Langan and Barnaby, 1998). Recent developments in new culture techniques, combined with increased market value and an abundant natural seed supply makes this species an ideal candidate for aquaculture development.

Sea Scallops *(Placopecten magellanicus)*

Though primarily an oceanic species, sea scallops can be found in the higher salinity areas of bays and estuaries in New England below a depth of 5 meters. Several scallop beds are located in the lower Piscataqua River and Portsmouth Harbor and include the area between Salamander Point and Fort Point, in Spruce Creek and off Fort McClarey in Kittery, Maine. Langan (1994) examined the density, size structure and movements of scallops in the Fort Point area using SCUBA surveys and mark and recapture studies. Mean density was 1.3 scallops/m2 and with the exception of few small (10-20 mm) individuals, the population had a normal distribution. Small scallops are difficult to see and may have been overlooked by divers. Scallop movement is greater for the 40-60 mm sized animals than smaller or larger individuals. Some large scallops were found within 100 meters of the release site a year after tagging. A project which began in 1996 (Langan 1997) is investigating the spawning time, spatfall and growth and mortality of scallops in suspension and bottom culture. The spawning period in 1996, based on gonadal/ somatic index (GSI), commenced in late July and spat settlement began in October. Onion bag/monofilament type spat collectors were used to capture larvae. Some collectors were retrieved in March and scallops from 4-10 mm were retrieved. These scallops and approximately one thousand 25 mm individuals were placed in suspension culture to measure growth and mortality. Natural enhancement of the bottom under the collectors was assessed in the summer of 1997.

Scallops are fished commercially with towed dredges from November 1 to April 14, and are harvested commercially and recreationally using SCUBA. Other than the 1994 survey at Fort Point, there is little information on scallop density or population change over time. Commercial fishermen indicate, however, that there is a great deal of variation in scallop abundance both temporally and spatially (P. Flanigan, personal communication).

Other Bivalve Species

Though there is no documented information on population densities and trends, several other bivalve species common to New Hampshire estuaries should be mentioned. The deposit feeding clam *Macoma balthica* is common in all areas of Great Bay and Hampton Harbor and the siphon of this clam is a favored prey item of juvenile winter flounder (Armstrong, 1996). Razor clams (*Ensis directus*) can be locally abundant in subtidal areas of Great Bay (Nelson, 1981), and the ribbed mussel (*Geukensia demissus*) is also common in lower salinity and marsh areas of the Great Bay (Nelson, 1981) and Hampton/Seabrook estuaries. The gem clam, *Gemma gemma*, a very small bivalve, can be the dominant infaunal taxon in the sandier areas of Great Bay.

3.1.3.2 Crustaceans

American Lobsters

The American lobster is the largest crustacean inhabiting New Hampshire's estuaries and coastal zone. They are the target of a large and valuable commercial fishery which will be discussed in a later section of this report. Though primarily a coastal and oceanic species, lobsters inhabit many coastal bays and estuaries. They range from the mid-Atlantic states through Newfoundland, though in their southern range, they are found in greatest abundance in deeper offshore waters. Though most often fished in shallow waters (<100 ft), lobsters inhabit waters as deep as 1,500 ft. Lobsters are omnivorous, feeding on molluscs, urchins, starfish, crabs and even other lobsters. They in turn are preyed upon by seals, groundfish (cod) and other large predatory fish such as striped bass. The adults undergo a seasonal migration, moving inshore in spring and offshore in the fall, though within that time period, they may move about a great deal within estuaries (Dr. S. Jury, personal communication). Spawning occurs by means of internal fertilization when the female has recently molted, and the fertilized eggs are extruded one year after molting. The females carry the fertilized eggs under their abdomen for up to one year. The eggs hatch and are released into the water column in late spring/early summer in near shore areas, and the planktonic larvae go through several molt stages before settling to the bottom. The preferred juvenile settlement substrate is rock-cobble, (Wahle and Steneck 1991, 1992) though older juveniles can be found inhabiting any type of substrate where shelter (boulders, rocks, cobble, mud burrows) can be found. Lobsters reach commercial size after 15-20 molts or in 6-9 years. Despite increased fishing pressure in recent years, lobster populations are relatively stable. More information on lobster abundance is presented in Chapter 4.

Crabs

Several species of crabs can be found in abundance in New Hampshire's estuaries and coastal areas. Most prominent are the rock crab (*Cancer irroratus*) and the green crab (*Carcinus maenas*) though the small mud crabs of the genera *Panopeus* and *Rhythropanopeus* are also very abundant. There is some commercial harvesting of rock crabs for human consumption and green crabs for bait, however, their economic importance is negligible.

3.1.3.3 Horseshoe Crabs *(Limulus polyphemus)*

The horseshoe crab (*Limulus polyphemus*) is not a true crab, and among the arthropods is more closely related to the arachnids (spiders, scorpions) than crustaceans. Horseshoe crabs are abundant in Great Bay and occur in lower numbers in Hampton Harbor. They are most conspicuous in the month of June, when they mate in large numbers during the spring flood tides and deposit their eggs on the beach. The eggs are preyed upon by several species of shore birds and represent a major food source for some species. Horseshoe crabs excavate large feeding pits in soft substrates, consuming the worms, molluscs and crustaceans.

mate of the amount of time it took to harvest one bushel of oysters prior to and after 1989. Seventy four percent of the respondents indicated that it took them longer to harvest their limit after 1989. A more recent survey in 1997 by NHF&G asked recreational harvesters their opinion about the general abundance of oysters in Great Bay. Fifty five percent expressed the opinion that the abundance was lower than in prior years, six percent thought is was higher, eighteen percent reported no change and seventeen percent didn't know. A commercial oyster harvester on the Maine side of the Piscataqua River ceased harvesting operations in 1995 after an epizootic of MSX caused mass mortalities of oysters in the Salmon Falls and Piscataqua rivers. Spinney Creek Shellfish, Inc. estimated 90% mortality in the Salmon Falls River beds, and 50-70% mortality in the Piscataqua River beds (T. Howell, personal communication). Data collected in the Salmon Falls and upper Piscataqua rivers in 1997 support these mortality estimates (Langan, unpublished data). Though systemic MSX infections in the Oyster River and Great Bay were lower, there is strong evidence, in the form of hinged or "boxed" oysters, to suspect that considerable disease related mortalities occurred in all areas of the Great Bay Estuary. More recent studies report the presence of MSX and dermo to be throughout the estuary (NHF&G, 1999).

As stated in another section of this report, larval recruitment and juvenile survival are important factors in maintaining oyster populations. Ayer et al. (1970) indicated that spat settlement in Great Bay was highly variable both spatially and temporally. They also reported that the percent of adult oysters spawning varies from year to year. Data collected by the Jackson Estuarine Laboratory from 1991 through 1996 indicates that light sets occurred in 1991, 1992 and 1996, a heavy set occurred in 1993 and virtually no set occurred in 1994 and 1995 (Dr. R. Langan, unpublished). The reasons for poor sets may be related to meteorological (temperature and salinity) and biological (sufficient food for adults and larvae, disease) conditions, but may also be related to the amount of available substrate for larval attachment. MacKenzie (1989) reported that the primary limiting factor in determining oyster recruitment is the amount of clean, hard substrate for larval attachment. With this in mind, it is interesting to note that the 1997 oyster harvester survey conducted by the Fish and Game found that only 27% of recreational harvesters return shell to the oyster beds. This would certainly support the concept that lack of available substrate for larval settlement is contributing to the poor spat settlement and juvenile recruitment. Though the lack of consistency in data collection makes it very difficult to be scientifically certain, it appears that oyster populations in the Great Bay Estuary have declined in recent years due to a combination of inconsistent recruitment and disease.

A long-term trend in oyster populations in the Great Bay Estuary is also difficult to determine since there is a lack of historical data. The report by Jackson (1944) certainly indicates that by the mid-twentieth century, oysters populations had declined significantly due to overharvesting, pollution and siltation. Though these conditions have improved greatly in recent years, it is unlikely that oyster populations have increased much since the 1940's. We may never know the original baseline of oyster abundance, however, it is probably safe to say that oyster populations in the Great Bay Estuary are a fraction of what they once were.

Diseases of the Eastern Oyster in New Hampshire

The oyster diseases MSX and Dermo, caused by the protozoan parasites *Haplosporidium nelsoni* and *Perkinsus marinus,* respectively, have recently been detected in oysters from the Great Bay Estuary. These diseases were once thought to be limited in their range by temperature and salinity to the mid-Atlantic region of the U.S., however their occurrence has expanded in recent years through New England and the disease organisms have been identified as far

Prevalence, systemic infection and MSX mortalities of oysters in the Great Bay Estuary, 1995. **TABLE 3.2**

Location	**Date**	**Mean Shell Height (mm)**	**Prevalence %**	**Systemic Infections %**	**Dead %**
Salmon Falls	10/27/95	81	81	50	83
Piscataqua (Power Lines)	10/27/95	74	70	25	64
Piscataqua (Sturgeon Creek)	10/27/95	75	65	40	42
Piscataqua (Stacy Creek)	10/27/95	77	45	10	25
Oyster River	12/18/95	103	50	30	NA
Adams Point	11/06/95	95	40	15	NA
Nannie Island	11/06/95	96	15	5	NA

north as the Damariscotta River in Maine. These diseases have had a major impact on oyster populations in the Gulf of Mexico (Dermo) and have crippled the oyster industries in Delaware and Chesapeake Bays (MSX and Dermo). Both diseases become more virulent during dry periods in the summer, when high temperature and salinity conditions persist. The method of transmission of MSX is unknown, though it is suspected that an intermediate host for the infectious life stage may be involved. Dermo can be transmitted directly from one oyster to another as well as by a wide variety of organisms included many bivalve species, though it appears to be infectious only to Eastern oysters

The first recorded MSX epizootic caused by the oyster parasite *Haplosporidium nelsoni* occurred in 1995 in the Great Bay Estuary (Barber et al., 1997), even though the parasite was identified in Piscataqua River oysters in 1983 (Sherburne and Bean, 1991) and again in 1994 (B. Barber, unpublished data). Unusual mortalities were observed in the Piscataqua River by Maine harvesters in August, 1995, and samples were examined for the *H. nelsoni* parasite. Samples of adult oysters (74-102 mm) were examined from beds in the Salmon Falls River, three sites in the Piscataqua River, the Oyster River, Adams Point and Nannie Island. The disease prevalence, percent of systemic infections and % dead from the disease are shown in Table 3.2. The disease caused the greatest mortalities in the Salmon Falls River and farthest upstream beds in the Piscataqua River, with lower prevalence and % systemic infections with increasing distance from the Piscataqua River. An examination of the climatological data, water temperature and salinity indicates that the conditions in 1995 were favorable for an MSX epizootic. Both temperature and salinity increased in all areas of the estuary from 1993 - 1995 due to drought conditions. The disease caused mortalities in all oyster beds and significant mortalities in some, and has had an impact on oyster populations that has not been fully assessed. Oyster samples from Nannie Island and Fox Point were analyzed in April, 1996. A 10% prevalence and no systemic infections were found. Samples of April, 1997, broodstock oysters from Fox Point were examined and a 17% prevalence of light infections was found. Observations of gaping and recently dead oysters from Nannie Island and Adams Point in the spring of 1997 (R. Langan, personal observation) indicates the possibility of continued mortalities from the disease despite the lower than average salinities in 1996 and the first half of 1997. A regular program of monitoring for *H. nelsoni* and *P. marinus* is underway (NHF&G, 1999).

The protozoan oyster parasite *Perkinsus marinus*, the causative agent of the Dermo disease, was identified in oysters from Spinney Creek, Maine in September, 1996. A large percentage of the oysters were infected, and some had heavy infections. No mortalities were attributed to the disease at that time. Additional samples were obtained in

December, 1997, from two sites in the Piscataqua River and Nannie Island in Great Bay. A "dermo-like" body was found in one of 25 oysters from Nannie Island, and 2 of 25 oysters from at Sturgeon Creek. A heavy infection was found in one of 25 oysters near the "three rivers" point in the Piscataqua River. No infected oysters were found (out of 25) at Seal Rock in the Piscataqua River. Thirty oysters from Fox Point were examined in March, 1997 and no infected oysters were found. Additional diagnostics have been conducted in the summer and fall of 1997. A low prevalence of light Dermo infections have been found in oysters from Adams Point, Nannie Island, and the Oyster River, while a higher prevalence and one oyster with advanced infection was found in the Piscataqua River. A neoplasia-like body was seen also by tissue examinations.

Belon or European Flat Oyster *(Ostrea edulis)*

The Belon oyster, native to Western Europe and the British Isles, was introduced into the Great Bay Estuary in the late 1970's by two commercial companies as an aquaculture species, and was grown in suspension culture in Little Bay, the Piscataqua River and Little Harbor, and in bottom culture in Spinney Creek. The Belon oyster prefers lower temperatures and higher salinities than the indigenous eastern oyster, and therefore habitat overlap is unlikely. Though similar in many respects to the Eastern oyster, *O. edulis* broods fertilized eggs internally, and releases larvae at the trochophore stage. Spinney Creek, where there is still active aquaculture of this species, has a spawning adult population capable of producing large natural sets of oysters, though few juveniles survive in Spinney Creek due to unfavorable temperatures in late summer. "Escapees" of this species have established natural, reproductive populations in the Piscataqua River, Portsmouth Harbor, Little Harbor, Rye Harbor, areas of the Back Bay in Portsmouth and more recently in Gosport Harbor at the Isles of Shoals. Though the actual numbers of this species is unknown, the fact that conditions are favorable for maintaining natural populations is interesting from a perspective of commercial aquaculture, since this species is highly valued and in great demand.

Softshell Clams *(Mya arenaria)*

Softshell clams are an infaunal bivalve that range from the mid-Atlantic region of the U.S. through the Canadian Maritimes. They can be found in substrates ranging from gravel to very soft mud, but appear to be most abundant in muddy or silty sand. Adults may burrow as deep as 20 cm into the substrate. They inhabit the intertidal and shallow subtidal areas of estuaries and coastal bays, and can tolerate a wide range of temperature and salinity. Though usually not a numerically dominant member of the infaunal community, in areas of high abundance they can represent a very large fraction of the infaunal biomass. Spawning occurs during two periods, spring and late summer-fall, though the greatest larval densities and greatest spat settlement occurs during the later spawning period. The larvae are planktonic for approximately 21 days. This species was also harvested commercially up to the mid 20th century, and is now the most popular recreational shellfish species in New Hampshire.

There is a great deal of uncertainty regarding abundances of softshell clams in the Great Bay Estuary. The locations of clam beds were reported by Nelson (1981) (Figure 3.1) and clam habitat, based primarily on suitability indices was recently mapped by the U.S. Fish and Wildlife (Banner and Hayes, 1996). Though clams can be found in most intertidal flats, densities are generally sparse and are spatially and temporally variable. There is some amount of recreational clamming in Great Bay, however, if a clammer were asked for his or her preferred location in New Hampshire, they would undoubtedly choose Hampton Harbor. Jackson (1944) reported acreage of flats in the Great Bay and the NH Fish and Game reported the location and abundance of clams in Great Bay (Nelson, 1981), Though seed clams were abundant at most sites, it appears that few survive since the abundance of larger size classes was low at all sites. The abundance of seed clams may have also been the result of a particularly heavy set that year. NH Fish and Game (1991) also reported acreage and standing crop of clams in the Great Bay Estuary in 1991. These data are presented in Table 3.3. A recent study provided more recent data on clam populations in the Great Bay Estuary (Langan, 1999). Results show moderate to high density of clams on the western flats of the Salmon Falls River and near Sandy Point in Great Bay, and low density on the eastern shore of lower Little Bay and along southern shoreline of Dover Point in Little Bay.

Jones and Langan (1996c) estimated clam abundance and spatfall on several flats in the Little Harbor area. They found that densities were generally low, despite the presence of suitable habitat, and that recent spatfall was poor. These data are presented in Table 3.4 and the locations of shellfish resources are shown in Figure 3.3. NH Fish and Game (1991) reported that there were 400 acres of clam flats in Little Harbor, the Back Channel area and in Sagamore Creek and a standing stock of 1,600 bushels of adult clams. A more recent report provides an updated database on clam populations in Back Channel (Langan et al., 1999b).

There is currently insufficient data to establish any trends in clam populations in Great Bay or Little Harbor. For a historical perspective, the report by Jackson (1944) stated that clams declined steadily in number between 1900 and 1944, and at that time there was "only a vestige of their former abundance," though no quantitative

Softshell clam flat acreage and abundance in Great Bay Estuary. **TABLE 3.3**

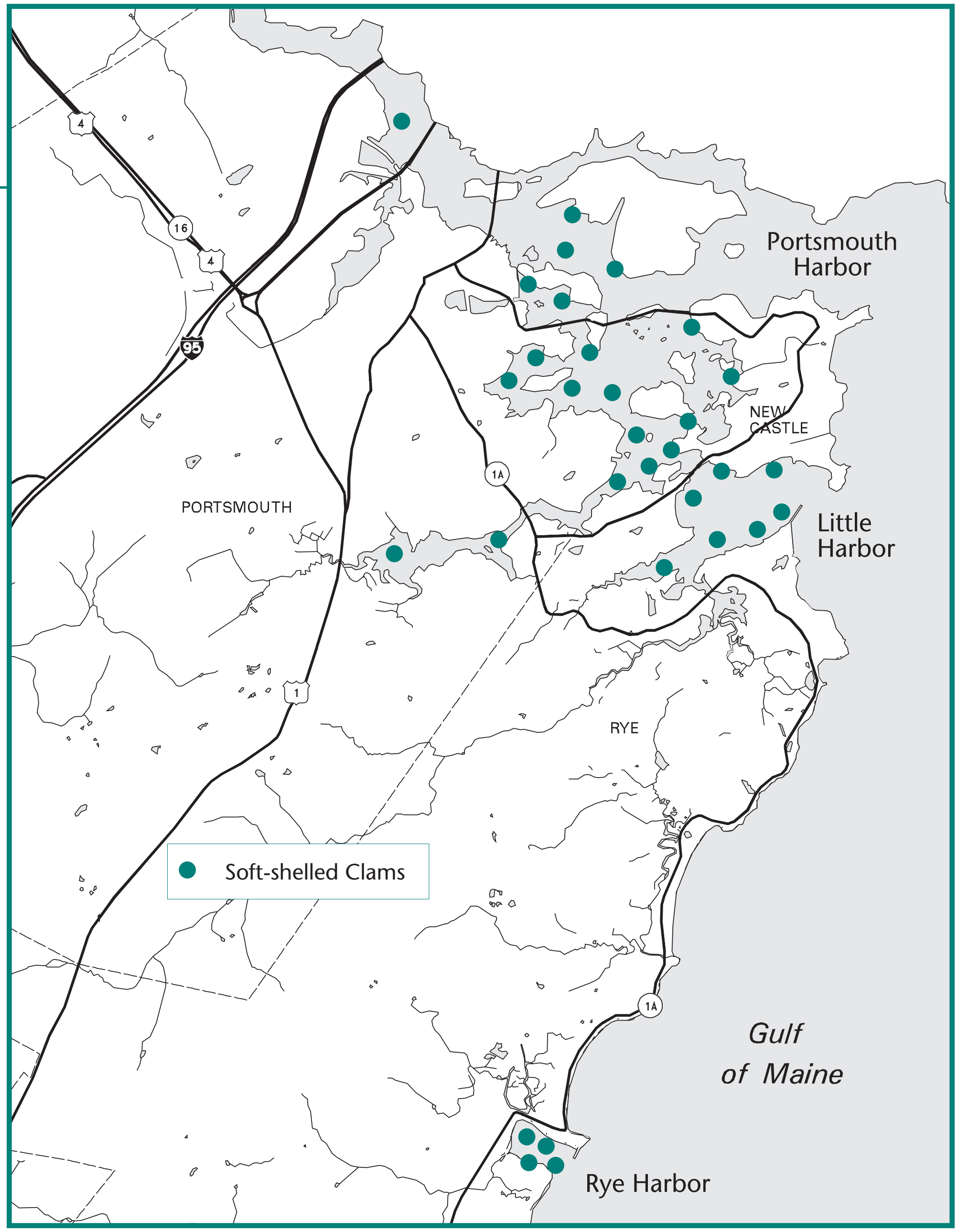
Location	Jackson (1944) Acreage	NH F&G (1991) Acreage	NH F&G (1991) Total Bushels
Salmon Falls River	125	125	500
Cocheco River	140	140	560
Piscataqua River	265	265	1060
Bellamy River	300	300	1200
Oyster River	225	225	900
Lamprey River	60	60	240
Squamscott River	180	180	720
Little Bay	430	380	1520
Great Bay	1000	500	2000
Total	2725	2175	8700

Softshell clam flat density and abundance in Little Harbor. **TABLE 3.4**

Clamflat No.	**Location**	**Acres**	**Density** #/m²	**Total Area** m²	**Abundance**	**# Bushels** 1200 clams/bu
1	Odiorne: West	0.4	1.6	1,618	2,589	2
2	Odiorne: East	8.6	4.4	34,796	153,102	18
3	Witch Creek: *Unsuitable substrate*					
4	Triangle	3.2	12:53	12,950	162,264	135
5	Wentworth	12.1	2.02	48,968	98,915	82
6	Seavey	6.4	5.07	25,900	131,313	1 09
7	Berrys Brook	4.2	4.65	18,817	87,499	73
Total		34.9	5.0	143,049	635,682	530

FIGURE 3.3

Shellfish resources in Portsmouth, Rye, and Little Harbors.



data are available for that period.

The locations of clam resources in Hampton Harbor are illustrated in Figure 3.4. Abundance and age composition of clams from the Hampton River Confluence, Common Island and Seabrook (middle ground) clam flats in Hampton Harbor have been monitored since 1974 by Normandeau Associates for the Public Service Company of New Hampshire as a requirement of their license to operate the Seabrook nuclear power plant. Larval abundance has been monitored for the same time period at a nearfield station outside the Harbor. This is without a doubt the most complete dataset for shellfish in New Hampshire and the long term data are presented in detail in the utilities' 1996 environmental report (NAI, 1996). Since only a summary of the information is presented here, the reader is referred to the referenced document for more detail.

Larval Abundance

Mya larvae are present in the water column from May through October and maximum densities are typically recorded in late summer or early fall with a secondary peak in early summer. This timing of the peak density can vary in timing and magnitude. Larval density has

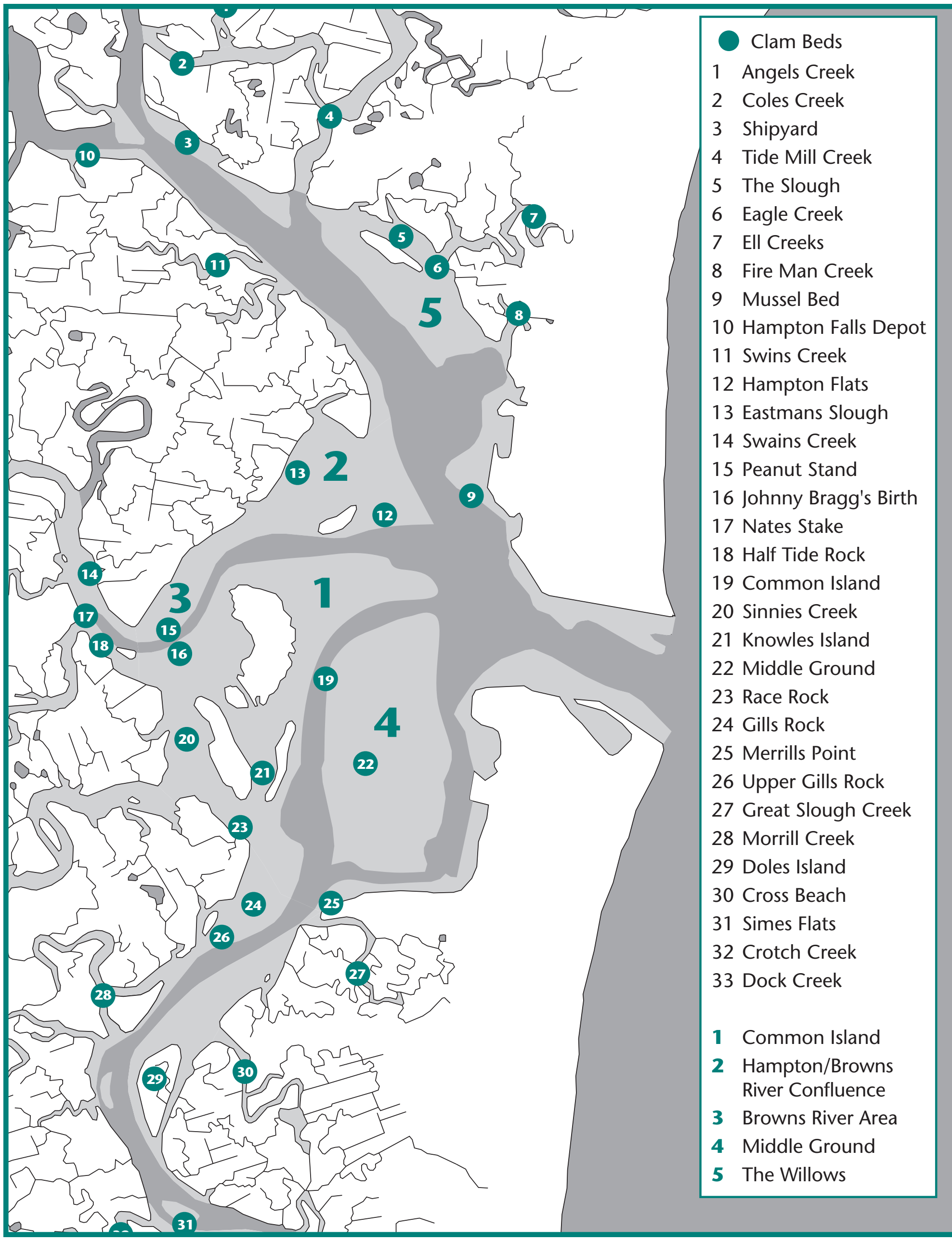


FIGURE 3.4

Shellfish resources in the Hampton Harbor Estuary.

been generally lower in the years 1991-1995 than in the period from 1978-1981. Gonadal studies indicate that spawning in Hampton Harbor usually follows the appearance of larvae at offshore stations, indicating that the early larvae are not produced by local broodstock. Based on the current patterns in the area, it is likely that recruitment of larvae of non-local origin occurs.

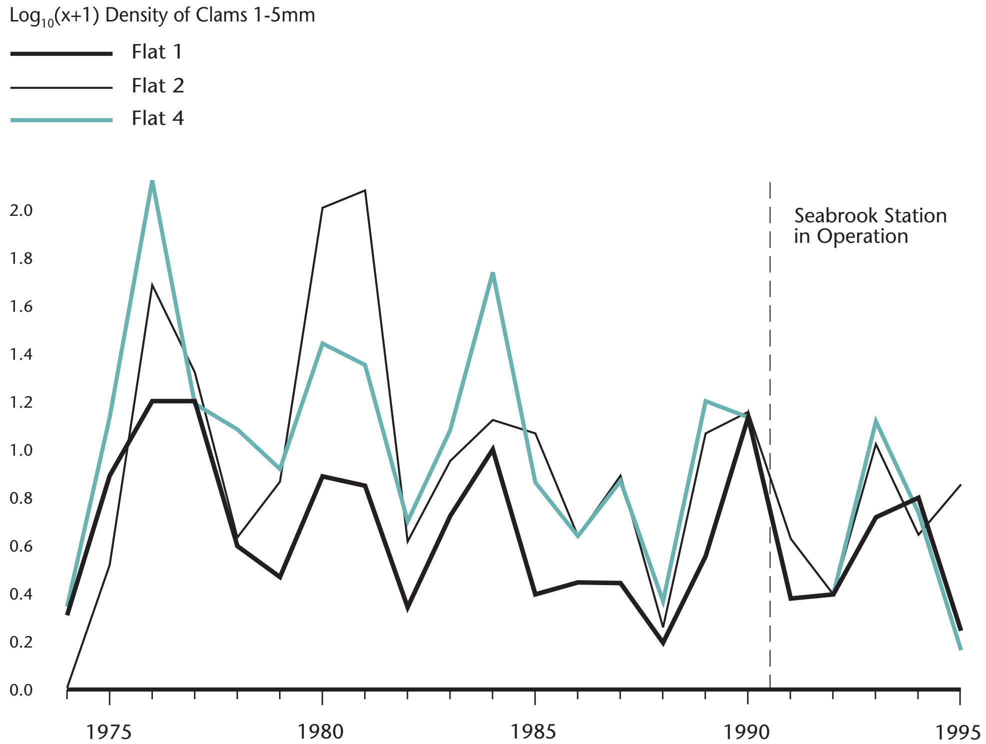
Young of the Year

Young of the year (YOY) clams are newly settled spat ranging from 1-5 mm. Historically YOY clam density has been highly variable both spatially and temporally in Hampton Harbor. In 1995, YOY density on the Seabrook Flat was lower than all years since 1974, while on the Hampton River confluence flat, density was higher than 1991-1994, but lower than the 1974-1989 average. Density was the second lowest since 1974 on the Common Island flat. Long term density appears to have declined slightly since 1974, and good sets appear to occur approximately every three to four years (Figure 3.5).

Spat

Density of spat (6-25 mm), or year one clams that have successfully overwin-

FIGURE 3.5 *Annual mean log10(x+1) density (number per ft2) of clams 1-5 mm length: 1974-1995. Data from NAI (1995)*



tered, has been variable for the study period, however, it can be stated that density on all flats was highest from 1977 through 1981, lowest from 1981 through 1989, and although much lower than the 1977-81 abundances, peaks in density occurred in 1990 and 1994. These peaks in density correspond well to the YOY densities except for the years from 1983 through 1987 where it appears that reasonably good sets did not survive the winter (Figure 3.6).

Juveniles

Juvenile clams (26-50 mm), are more than likely two year old clams. The annual density of juveniles corresponds well with spat density with a one year lag time. Clams of this size were most abundant from 1979-1981, and have declined steadily since, though smaller peak densities were recorded in 1990 and 1995 (Figure 3.7).

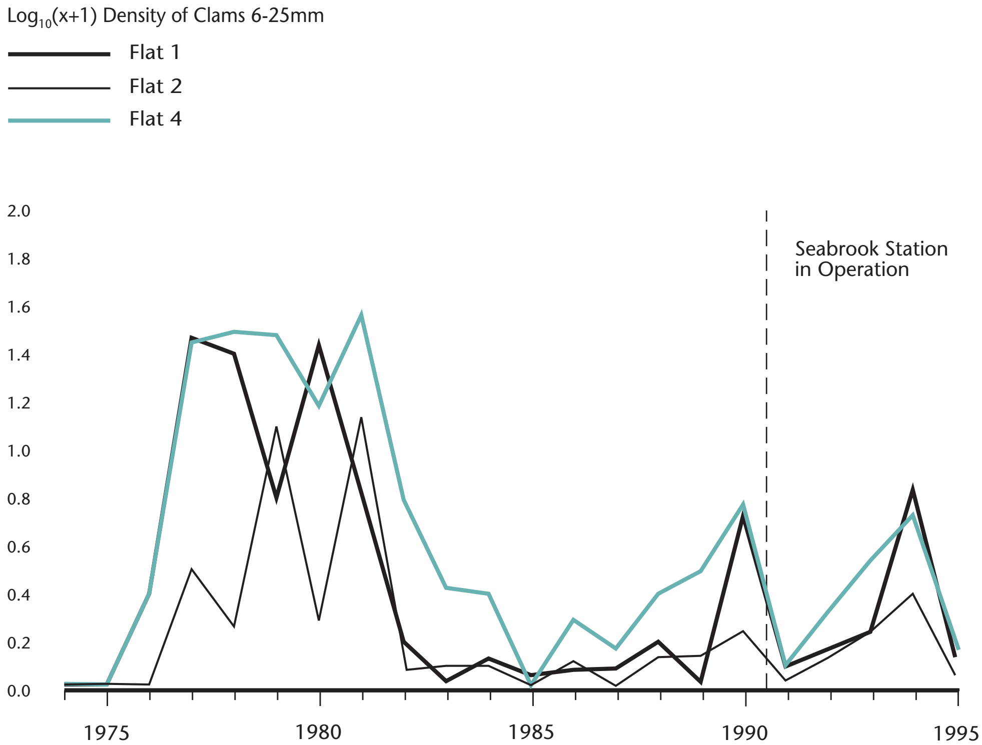
Adults

Adult clams (>50 mm) were abundant in 1971 through 1975 (Savage and Dunlop 1983), declined from 1976-1979, and reached peak abundances from 1980-1984. The steady sharp decline in abundance beginning in 1984 was very likely due to heavy harvest pressure. A classic predator prey relationship, where the change in density of prey is tracked by a change in predator density (with some lag period), exists between the clam population and the number of adult clam licenses sold (Figure 3.8). Closure of the flats in 1989 resulted in minor recovery of adult clam density on the Common Island flat from 1989 to 1995, a much greater increase in density in clams on the Seabrook flat, and little change on the Hampton River confluence flat, though an increase was recorded from 1994-1995. The Common Island flat was reopened in 1994, however the effects of recreational clamming in 1994 and 1995 appeared to have little effect on clam density (Figure 3.9). A recent study focused on removing blue mussels from flats to improve clam habitats (Langan and Barnaby, 1998).

Predation, particularly of small clams, can greatly affect the survival of clams to harvestable size. The green

Annual mean log10(x+1) density (number per ft2) of clams 6-25 mm length: 1974-1995. Data from NAI (1995).

FIGURE 3.6



Annual mean log10(x+1) density (number per ft2) of clams 26-50 mm length: 1974-1995. Data from NAI (1995).

FIGURE 3.7

FIGURE 3.8

Number of clam licenses and the adult clam standing crop (bushels) in Hampton-Seabrook Harbor: 1971-1987. Data from NAI (1995).

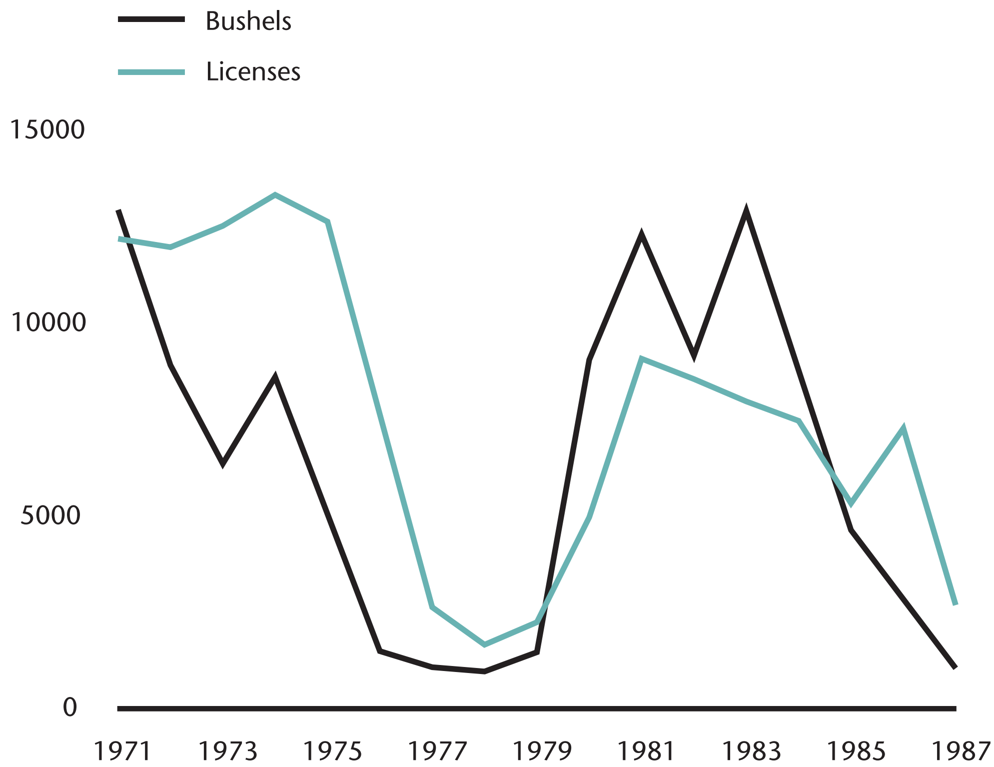
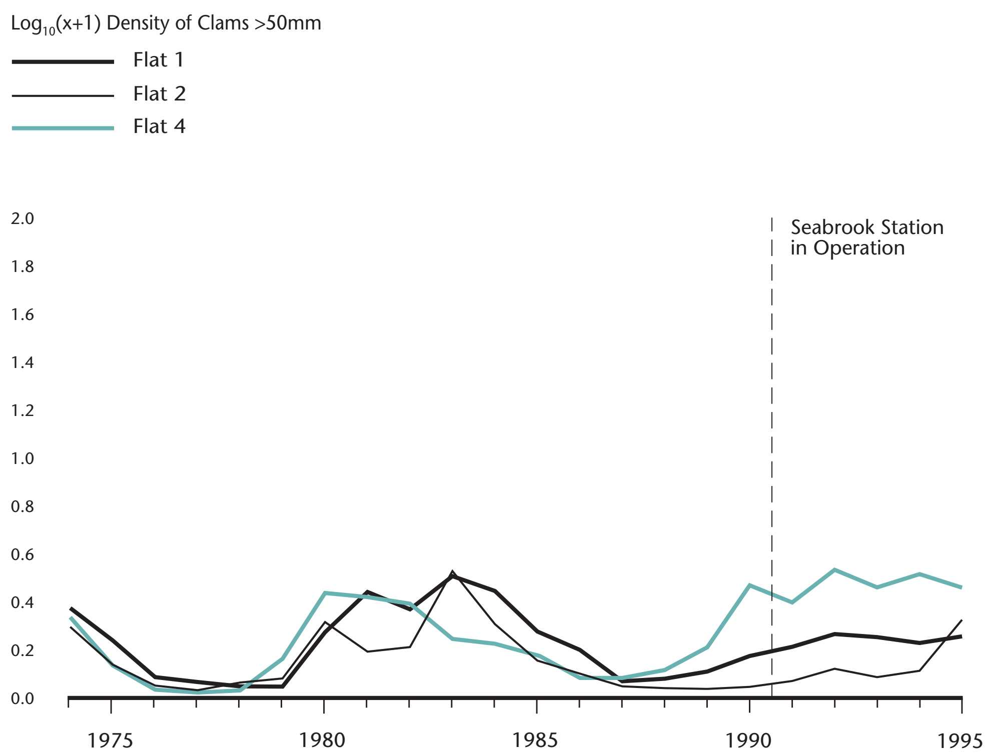


FIGURE 3.9

Annual mean log10(x+1) density (number per ft2) of clams >50 mm length: 1974-1995. Data from NAI (1995).



crab, a major predator of *Mya*, has been highly variable over time in Hampton Harbor, but unlike human predators, their numbers are influenced by minimum winter water temperatures rather than prey (clam) abundance. Even in years of low crab abundance, there appears to be sufficient numbers of crabs in the Harbor to impact juvenile clam abundance. Other predators include nematodes, horseshoe crabs and birds. Though massive sets of clams could "breakthrough" and overwhelm predation pressure, it is unlikely that this will happen without substantial natural or artificial reseeding and predator protection (Savage and Dunlop, 1983).

Ultimately, it appears that the controlling factors determining clam populations in Hampton Harbor are larval settlement, predation, prevalence of sarcomatous neoplasia (Hampton River flat) and harvest pressure. Savage and Dunlop (1983) stated that unless and seed clams are protected from predators and harvest pressure on adult clams is controlled, it would be very difficult for even large sets of clams to overcome the rate of predation and produce increased quantities of adult clams.

Softshell Clam Diseases: Sarcomatous neoplasia

Sarcomatous neoplasia, a lethal form of leukemia in clams, has the potential to cause serious mortalities in the softshell clams. The infection has been observed in relatively pristine waters, however it is suspected that the rate of infection is enhanced by pollution.

Sarcomatous neoplasia was observed in Hampton Harbor clam populations in October, 1986 and February, 1987 from the Common Island (6%) and Hampton River confluence (27%) flats (NAI, 1996). No infections were found on the Seabrook flat (middle ground). Clam surveys in 1987 indicated that juvenile and adult densities were reduced by 50% in the two flats where disease was identified, while the population was unchanged on the middle ground. It is suspected that the reduced densities resulted from disease related mortalities. In November, 1989, twelve of fifteen clams (80%) from the Hampton River were infected. From 1990-1995, adult clam densities quadrupled in the middle ground, while Common Island densities did not change, and Hampton River density decreased by 50%. It is suspected that disease may have contributed to the observed reductions. Clams in the Great Bay Estuary have not been examined for neoplasia.

Blue Mussels *(Mytilis edulis)*

The blue mussel is widely distributed in the North Atlantic and occurs in Europe as well as North America. On the East Coast of the U.S., it ranges from Cape Hatteras to the Arctic Circle. Mussels inhabit the intertidal and subtidal zones of estuaries and the open coast. Though primarily a shallow water species, they are sometimes found at considerable depths. They can tolerate temperatures ranging from -2°C to 25°C and salinities ranging from 5 ppt to 35 ppt, though prolonged expose to salinities below 15 ppt are lethal. Spawning can occur year round, though the peak spawning period is June through August. Like other bivalves, the larvae are planktonic and remain in the water column for three to five weeks. Initial settlement occurs in shallow water on any firm substrate, however, newly attached juvenile mussels can detach their byssal threads and drift with the currents in search of other suitable attachment surfaces. Though mussels are harvested in large quantities and are an important aquaculture species in Europe, Canada and other parts of the world, they are largely ignored as a food species in New England. They are considered by many to be a nuisance species since colonization leads to fouling of industrial and coastal structures, as well as the hulls of ships.

Blue mussels can be found in the Great Bay Estuary attached to any hard substrate in the intertidal and subtidal zones, and also colonize intertidal flats in scattered clumps and contiguous mats. Though during high salinity periods mussels may be found in most areas of the estuary, their limited tolerance for low salinity limits their permanent upstream distribution to the area around Dover Point. Mussels are most abundant in the lower Piscataqua River, Portsmouth Harbor and Little Harbor. The location of some mussel beds in the lower estuary was identified as part of the Ecological Risk Assessment study for the Portsmouth Naval Shipyard. Density, size and condition index of mussels from a number of sites was measured for this study (Johnston et al., 1994). Banner and Hayes (1996) mapped blue mussel habitat using a suitability index model, however, the lower estuary where mussels are most abundant was not included in their study.

Long term records of larval abundance and juvenile settlement of blue mussels have been maintained as part of the PSNH environmental studies program by Normandeau Associates (NAI, 1996). Mussel larvae are a dominant taxon in the nearshore plankton community and are the dominant noncolonial taxon on shallow depth fouling panels. Density of larvae has increased in recent years, and though settlement varies annually, in general it has increased in recent years as well. Mussels can be found in the estuary attached to hard substrate in both the intertidal and subtidal zones, and can form extensive beds on tidal flats. Banner and Hayes (1996) have mapped mussel habitat using occurrence and suitability indices. The most prominent beds are located in the Hampton River, Blackwater River, and on the Seabrook middle ground clam flat. There is no scientifically documented change in abundance, though there is information (P. Tilton, personal communication) that the coverage of mussels on the Seabrook flat has increased in recent years. Mussel density on the flats in Seabrook can be as high as 3500/m^2 (Langan and Barnaby, 1998). Recent developments in new culture techniques, combined with increased market value and an abundant natural seed supply makes this species an ideal candidate for aquaculture development.

Sea Scallops *(Placopecten magellanicus)*

Though primarily an oceanic species, sea scallops can be found in the higher salinity areas of bays and estuaries in New England below a depth of 5 meters. Several scallop beds are located in the lower Piscataqua River and Portsmouth Harbor and include the area between Salamander Point and Fort Point, in Spruce Creek and off Fort McClarey in Kittery, Maine. Langan (1994) examined the density, size structure and movements of scallops in the Fort Point area using SCUBA surveys and mark and recapture studies. Mean density was 1.3 scallops/m2 and with the exception of few small (10-20 mm) individuals, the population had a normal distribution. Small scallops are difficult to see and may have been overlooked by divers. Scallop movement is greater for the 40-60 mm sized animals than smaller or larger individuals. Some large scallops were found within 100 meters of the release site a year after tagging. A project which began in 1996 (Langan 1997) is investigating the spawning time, spatfall and growth and mortality of scallops in suspension and bottom culture. The spawning period in 1996, based on gonadal/ somatic index (GSI), commenced in late July and spat settlement began in October. Onion bag/monofilament type spat collectors were used to capture larvae. Some collectors were retrieved in March and scallops from 4-10 mm were retrieved. These scallops and approximately one thousand 25 mm individuals were placed in suspension culture to measure growth and mortality. Natural enhancement of the bottom under the collectors was assessed in the summer of 1997.

Scallops are fished commercially with towed dredges from November 1 to April 14, and are harvested commercially and recreationally using SCUBA. Other than the 1994 survey at Fort Point, there is little information on scallop density or population change over time. Commercial fishermen indicate, however, that there is a great deal of variation in scallop abundance both temporally and spatially (P. Flanigan, personal communication).

Other Bivalve Species

Though there is no documented information on population densities and trends, several other bivalve species common to New Hampshire estuaries should be mentioned. The deposit feeding clam *Macoma balthica* is common in all areas of Great Bay and Hampton Harbor and the siphon of this clam is a favored prey item of juvenile winter flounder (Armstrong, 1996). Razor clams (*Ensis directus*) can be locally abundant in subtidal areas of Great Bay (Nelson, 1981), and the ribbed mussel (*Geukensia demissus*) is also common in lower salinity and marsh areas of the Great Bay (Nelson, 1981) and Hampton/Seabrook estuaries. The gem clam, *Gemma gemma*, a very small bivalve, can be the dominant infaunal taxon in the sandier areas of Great Bay.

3.1.3.2 Crustaceans

American Lobsters

The American lobster is the largest crustacean inhabiting New Hampshire's estuaries and coastal zone. They are the target of a large and valuable commercial fishery which will be discussed in a later section of this report. Though primarily a coastal and oceanic species, lobsters inhabit many coastal bays and estuaries. They range from the mid-Atlantic states through Newfoundland, though in their southern range, they are found in greatest abundance in deeper offshore waters. Though most often fished in shallow waters (<100 ft), lobsters inhabit waters as deep as 1,500 ft. Lobsters are omnivorous, feeding on molluscs, urchins, starfish, crabs and even other lobsters. They in turn are preyed upon by seals, groundfish (cod) and other large predatory fish such as striped bass. The adults undergo a seasonal migration, moving inshore in spring and offshore in the fall, though within that time period, they may move about a great deal within estuaries (Dr. S. Jury, personal communication). Spawning occurs by means of internal fertilization when the female has recently molted, and the fertilized eggs are extruded one year after molting. The females carry the fertilized eggs under their abdomen for up to one year. The eggs hatch and are released into the water column in late spring/early summer in near shore areas, and the planktonic larvae go through several molt stages before settling to the bottom. The preferred juvenile settlement substrate is rock-cobble, (Wahle and Steneck 1991, 1992) though older juveniles can be found inhabiting any type of substrate where shelter (boulders, rocks, cobble, mud burrows) can be found. Lobsters reach commercial size after 15-20 molts or in 6-9 years. Despite increased fishing pressure in recent years, lobster populations are relatively stable. More information on lobster abundance is presented in Chapter 4.

Crabs

Several species of crabs can be found in abundance in New Hampshire's estuaries and coastal areas. Most prominent are the rock crab (*Cancer irroratus*) and the green crab (*Carcinus maenas*) though the small mud crabs of the genera *Panopeus* and *Rhythropanopeus* are also very abundant. There is some commercial harvesting of rock crabs for human consumption and green crabs for bait, however, their economic importance is negligible.

3.1.3.3 Horseshoe Crabs *(Limulus polyphemus)*

The horseshoe crab (*Limulus polyphemus*) is not a true crab, and among the arthropods is more closely related to the arachnids (spiders, scorpions) than crustaceans. Horseshoe crabs are abundant in Great Bay and occur in lower numbers in Hampton Harbor. They are most conspicuous in the month of June, when they mate in large numbers during the spring flood tides and deposit their eggs on the beach. The eggs are preyed upon by several species of shore birds and represent a major food source for some species. Horseshoe crabs excavate large feeding pits in soft substrates, consuming the worms, molluscs and crustaceans.

ESTUARINE FINFISH

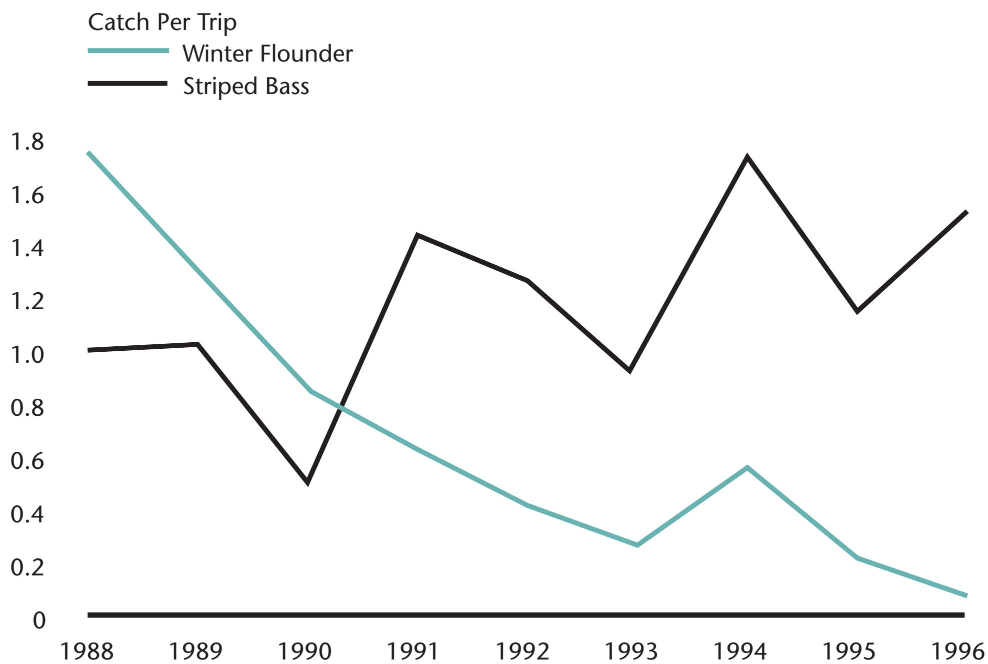
Coastal New Hampshire and its estuaries were well known for their variety and abundance of finfish species in colonial times. In fact, the area's earliest settlements were established in order to exploit the bountiful stocks of finfish. Throughout the eighteenth and nineteenth centuries, overharvesting, the construction of tidal dams, destruction of spawning grounds through sedimentation and municipal and industrial pollution greatly reduced their numbers in the Great Bay Estuary (Jackson 1944). As conditions improved toward the latter part of this century, many species have re-established themselves since 1900. Today the Great Bay Estuary supports 52 species of resident and migratory fish (Nelson, 1981) which are listed in Appendix E, while twenty eight species were reported for Hampton Harbor (NAI, 1977). Estuarine species include year round resident such as tomcod (*Microgadus tomcod*), mummichogs (*Fundulus* sp.) and silversides (*Menidia menidia*), seasonal migrants such as bluefish (*Pomatomus saltatrix*) and striped bass (*Morone saxatilis*) and anadromous fish such as the river herrings (*Alosa pseudoharengus* and *A. aestevalis*), shad (*Alosa sapisissima*) and lampreys (*Petromyzon marinus*) (Jackson, 1944; Nelson,1981, 1982; Sale et al., 1992; Jury et al., 1994). Fishways constructed on the Cocheco (2), Exeter (2), Oyster, Winnicut and Lamprey rivers in the Great Bay Estuary have enabled populations of several anadromous species to rebound, however, some species such as Atlantic salmon, and the common and shortnosed sturgeons (for which there is no reliable historic record of occurrence) and shad have not successfully been reestablished, despite stocking efforts for Atlantic salmon and shad. Commercially and recreationally important species, include smelt, (*Osmerus mordax*), winter flounder, *(Pleuronectes americanus*), smooth flounder (*Liopsetta putnami*), and striped bass, (*Morone saxatilis*). Finfish occurrence, abundance and ecology have been studies by many groups including the NH Fish and Game, Normandeau Associates, Inc, the University of New Hampshire, U.S. Fish and Wildlife, and the National Oceanic and Atmospheric Administration (NOAA) as part of natural resource inventories, impact assessments for power plants and ecological research projects. Detailed information on estuarine and coastal finfish species can be found in Jackson (1994), Nelson (1981, 1982), Sale et al. (1992), Jury et al. (1994), NAI (1977 and 1996) and fish habitat has been mapped in G.I.S. format by the U.S. Fish and Wildlife Gulf of Maine Project (Banner and Hayes, 1996). Finfish research and monitoring by NH Fish and Game, Normandeau Associates the University of New Hampshire continues today, and provides updated information on finfish abundance. The status and trends of finfish species selected for their commercial, recreational and ecological importance are described below.

3.2.1 SELECTED SPECIES

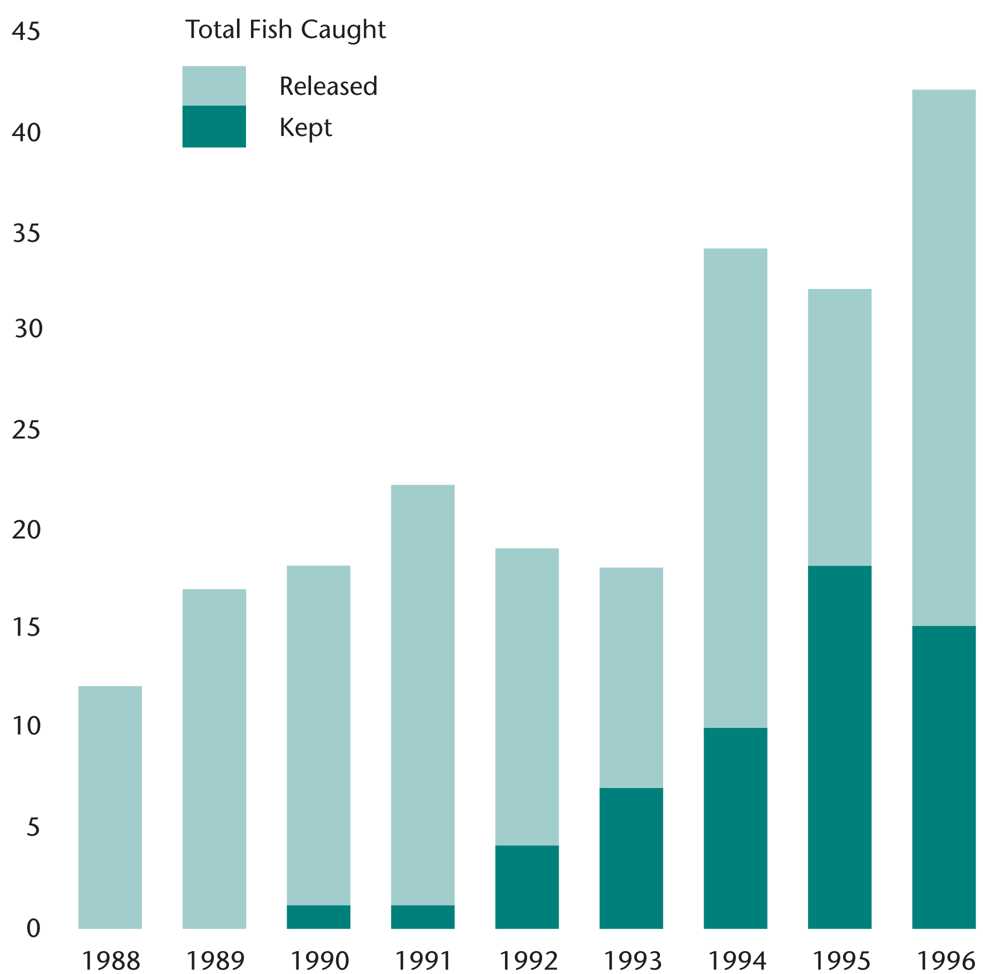
3.2.1.1 Striped Bass (*Morone saxatilis*)

As a result of the region-wide moratorium and subsequent harvest restrictions on striped bass in the 1980's and 1990's, New Hampshire waters have experienced a tremendous increase in the seasonal occurrence of this species. Striped bass abundance has increased steadily since 1988. Though the data presented in Figure 3.10 are based on NH Fish and Game creel surveys and the size frequency of the fish are not noted, there is general agreement among biologists and anglers that fish of all sizes have increased in abundance. Fish begin to arrive in mid to late May and remain in the estuary until October. It is not known if the same fish stay for the entire period or of there is a continual immigration and emigration of individuals during this period. Catches of fish in the winter and early spring indicate that some fish may overwinter in the Great Bay Estuary. Catches of legal (> 32") and undersized fish tagged by the U.S. Fish and Wildlife

Catch per trip of striped bass and winter flounder. Based on survey information. **FIGURE 3.10**



Striped bass caught in New Hampshire with U.S. Fish and Wildlife Service tags: 1988-96. **FIGURE 3.11**



Service have shown the same increase since 1988 (Figure 3.11).

Detailed information on striped bass population status and trends for Hampton Harbor is not available, though some of the data in Figures 3.5 and 3.6 would include fish captured in or near Hampton Harbor.

3.2.1.2 Winter Flounder *(Pleuronectes americanus)*

The recreational CPUE of winter flounder in Great Bay declined from 1988 to 1996, although CPUE was higher in 1995 and 1996 than in 1994 (Figure 3.10). Similar declines in abundance have been observed in Hampton Harbor. Larger individuals of this species are not year round estuarine residents and undertake regular migrations out of the estuary in the fall and return in the spring. Juvenile fish can be found in the estuary in all months, though their abundance is greatest from May through September. Winter flounder are subjected to very high fishing pressure in the nearshore (>3, <25 miles) and offshore (>25 mi) waters and the commercial CPUE in the Gulf of Maine has declined dramatically since 1982, after an increase from 1974 to 1982 (NOAA 1992). Studies by Armstrong (1995) and Langan (1994, 1996) found that juvenile winter flounder are abundant in the estuary in spring and summer, and forage in many different habitats. There is no clear preference for any one habitat and they can be found in the intertidal zone at high tide as well as in channel bottom in deeper areas of Great Bay. Using an otter trawl Armstrong (1995) averaged eight winter flounder per 10 minute tow in mid Great Bay from 1989 to 1992. Langan (1996), using the same type of fishing gear in the same location averaged 7.9 flounder per 10 minute tow in 1996. The size frequency distribution was similar for the two studies. Fish were collected in September, 1991 (Johnston et al., 1993) and in the spring of 1993 (Langan 1994) in the lower estuary as part of the Ecological Risk Assessment for the Portsmouth Naval Shipyard. In 1991, a series of five minutes tows yielded from 0 to 11 winter flounder per five minute tow. Highest densities were found in the Clark Island embayment and near Fishing Island. Mean length frequency varied by station, ranging from < 100 mm to nearly 300 mm. Trawls and seine hauls in 1993 at similar stations yielded up to fifty small flounder per seine haul in shallow water near Fishing island, the Kittery back channel, Clark Island embayment and the Police Dock area of Seavey Island. The mean size of fish captured in seine hauls was 57 mm. Larger fish were captured with an otter trawl in the back channel and Clark Island Embayment. A total of 48 fish were captured in 10 five minute tows, with a mean size of 366 mm.

Though juvenile fish appear to be abundant in the estuary, the recreational angler CPUE has declined in recent years. This is no doubt attributable to stock depletion from heavy commercial harvest pressure in the Gulf of Maine.

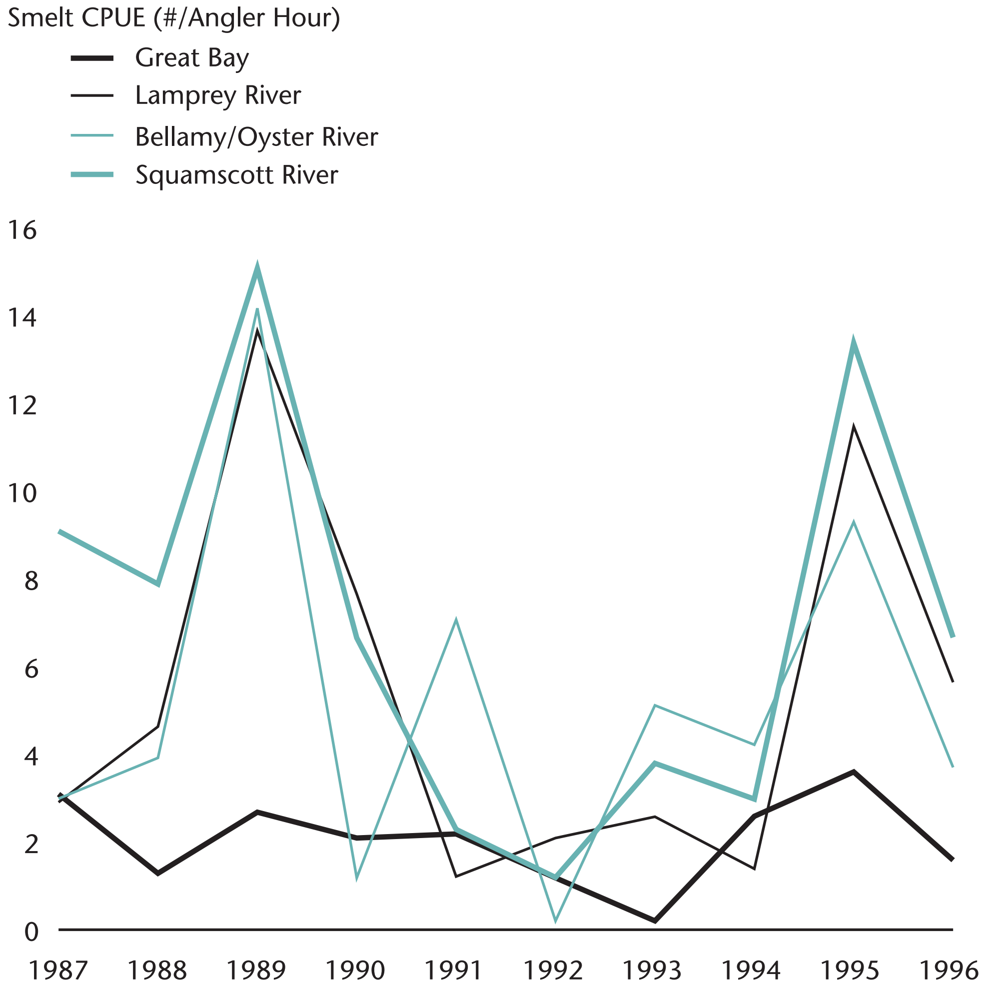
Catches of winter flounder at three stations in the Hampton/Seabrook Estuary have declined since 1980, though they have remained somewhat stable since 1987. The reason for the decline is attributable to overexploitation by commercial fishing in the Gulf of Maine (NAI, 1996)

3.2.1.3 Rainbow Smelt *(Osmerus mordax)*

The rainbow smelt is a common species in the Great Bay Estuary and is fished through the ice by commercial and recreational fishermen in the winter. They are an anadromous species that enter the estuary in fall and winter and ascend the tidal rivers in the Great Bay Estuary after ice-out to spawn. Based on angler CPUE, the abundance of smelt has been highly variable from 1987 to 1996 (Figure 3.12). CPUE reached a low point in 1992 and increased from 1993-1996. Average smelt egg deposition measured in the upper tidal reaches of the rivers from 1979 through 1996 has also been highly variable. Predation by striped bass may affect smelt populations.

Rainbow smelt abundance has been monitored by seine hauls at three sites in

Smelt CPUE by area (number caught per angler hour): 1987-1996. **FIGURE 3.12**



Hampton Harbor. Though abundance has been variable for the 19 year period (1976-1995), there is no discernible trend. The greatest abundances was measured in 1990, 1979, 1984, 1993 and 1994, and lowest abundances in 1978, 1980, 1992 and 1995.

3.2.1.4 River Herring: Alewife *(Alosa pseudoharengus)* and Blueback *(Alosa aestovalis)*

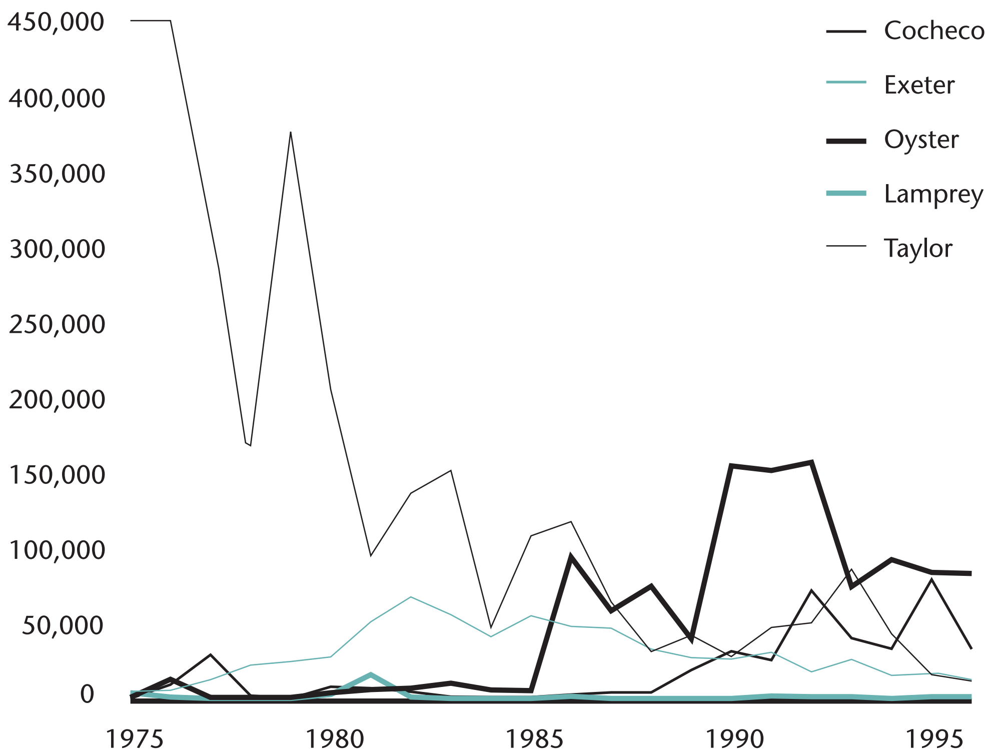
River herring (two species) are anadromous fish that migrate into the Great Bay Estuary in the spring and ascend the bay's tributaries to spawn. Though dams prevented these fish from reaching the freshwater portions of the rivers for many years, the construction of fishways in the 1970s has enabled passage of the fish to freshwater.

The NH Fish and Game has monitored spring returns of river herring at fishways in the Cocheco, Exeter, Lamprey, Oyster and Taylor (Hampton Harbor) rivers since 1975. Returns to the Exeter, Lamprey and Taylor rivers show a decline in numbers, while the Cocheco and Oyster rivers show an increase (Figure 3.13). The most dramatic decline has been in the Taylor River. The reason for the declines in some rivers is unknown, though predation by striped bass and changes in water flow may be factors. This species is also fished commercially for bait by offshore and inshore gillnetters. Records for catches by holders of inland netters permits are available.

3.2.1.5 American Shad *(Alosa sapidissima)*

Spawning adult American shad have been stocked from 1980 to 1995 in the Lamprey and Exeter rivers, and from 1980-1988 in the Cocheco and Lamprey

FIGURE 3.13 *River herring returns in Seacoast rivers: 1975-1996.*



rivers. Numbers stocked in the Exeter River increased each year since 1980, however this has not been reflected in the number of returning fish (Figure 3.14). A large number of fish returned to the Lamprey River in 1988, however few have returned since. The best ratio of returning to stocked fish has been realized for the Cocheco River, where the fewest adult fish were stocked. It may be possible that returning shad are intercepted by commercial gillnetters in the Gulf of Maine. Though the flesh is generally not consumed, the roe are considered a delicacy. The springtime harvest of shad in local offshore waters may be affecting the returns.

3.2.1.6 Atlantic Silversides *(Menidia menidia)*

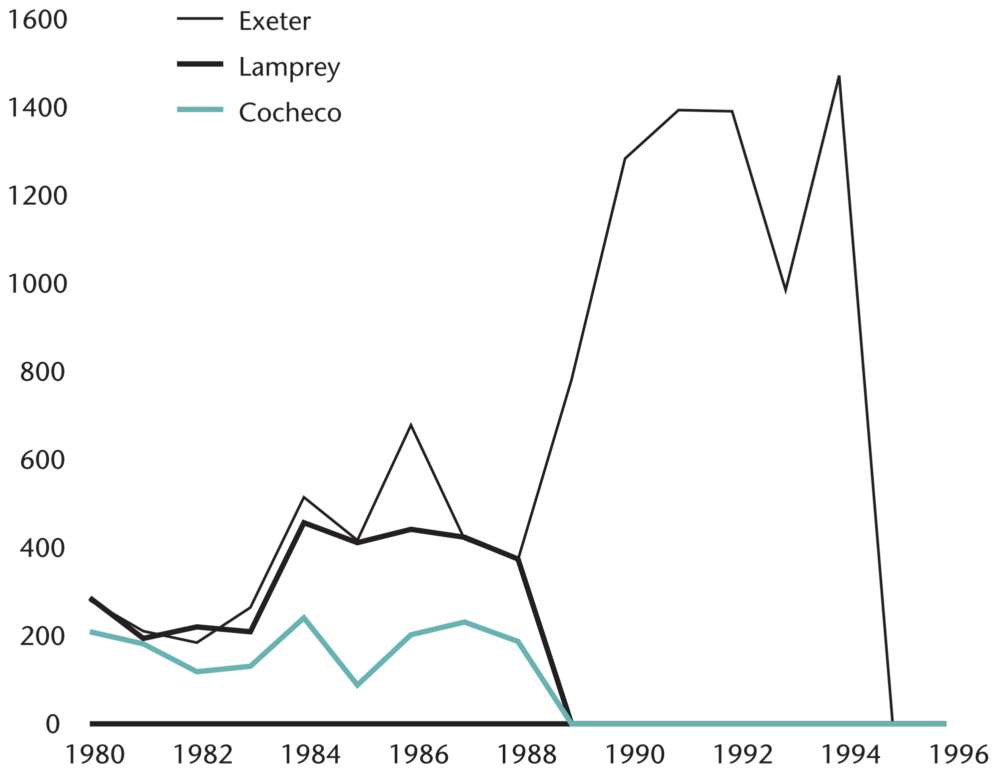
Silversides are a small, short-lived, and highly abundant estuarine species that are found in both Great Bay and Hampton Harbor. They generally inhabit shallow waters and are an important prey species for larger predatory fish. In the 1980-81 Fish and Game surveys (Nelson, 1982), they were the most abundant fish species captured in shallow waters and often represented >50% of the total catch. Young striped bass (12-24") have been observed to feed heavily on silversides in the Great Bay Estuary. The abundance of silversides has not been moni- tored in recent years, therefore it is not possible to determine trends in abundance.

The abundance of Atlantic silversides has been monitored by seining at three stations in Hampton Harbor from 1976 to 1995, though the years 1984-1987 were not sampled (NAI, 1996). A decline in abundance beginning in 1982 from the peak abundances during the period 1976-1981 was observed. Since 1982, the population has shown some interannual variation, but appears to have changed little to the present (Figure 3.15).

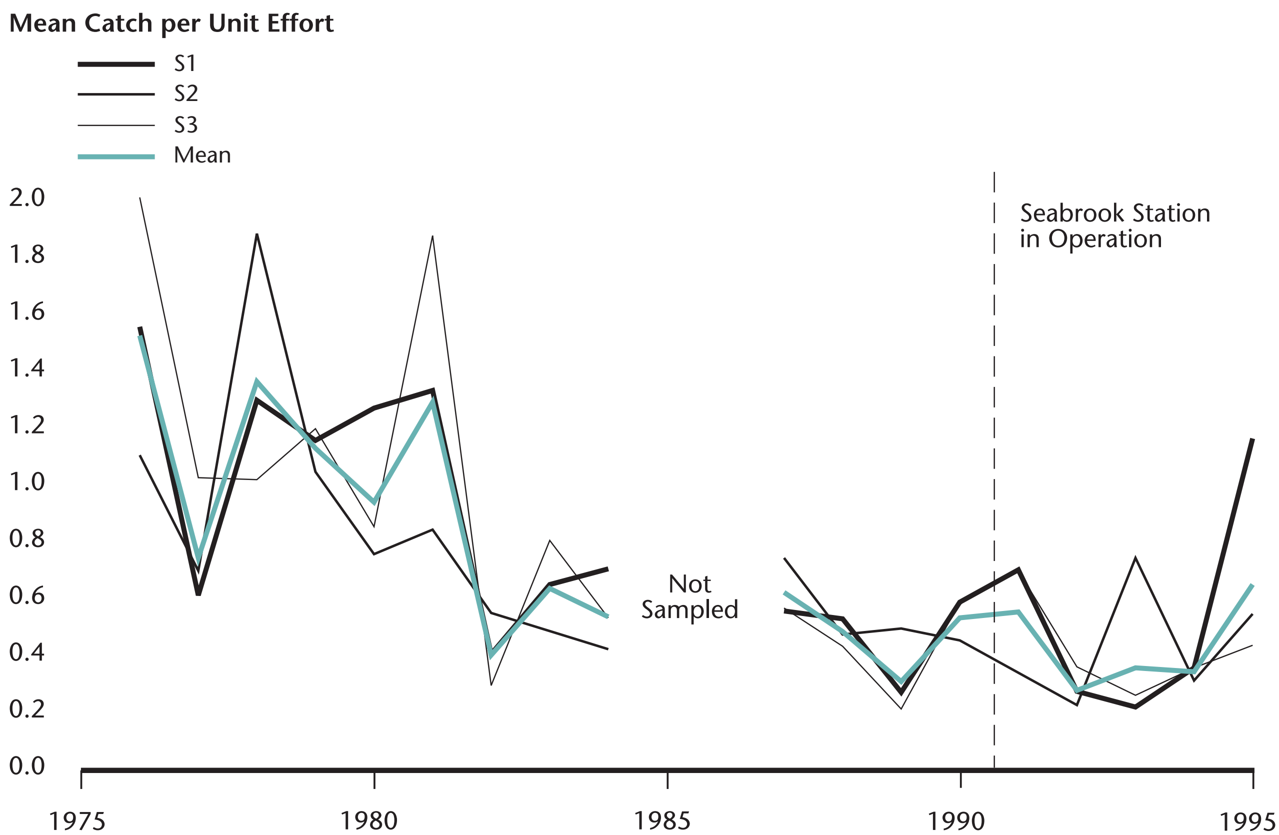
3.2.1.7 Atlantic Salmon *(Salmo salar)*

Although once abundant, the anadromous Atlantic salmon is uncommon in coastal New Hampshire, except as a stocked species. Overexploitation, the destruction of spawning grounds by sawdust and sediments in the 1800s, and

Number of spawning adult American shad stocked in the coastal rivers of New Hampshire: 1980-1996. **FIGURE 3.14**



Annual geometric mean catch of Atlantic silversides per unit effort in Hampton Harbor in seine samples (number per haul) for three stations and the combined mean of all stations: 1976-1995. **FIGURE 3.15**



dam construction resulted in the cessation of any natural runs of Atlantic salmon. The decline in Atlantic salmon populations is regional rather than local, and only a few native spawning runs remain in some Maine rivers. Atlantic salmon alevins have been stocked in tributaries to Great Bay since 1989, and some adults have been stocked in recent years. However the success of the program is yet to be determined.

3.2.2 Fish Kills

In the past several years three incidents of fish kills have been reported in the Great Bay Estuary, all involving alewives (*Alosa pseudoharengus*). In 1993, a school of alewives ascended a temporary spillway created by a pond draw down from the Exeter Water Works. The fish ascended the spillway to the pond from which there was no means of escape. The fish depleted the oxygen in the pool and 375-450 fish died as a result. Mr. Virgil Harris of the Exeter Water Department reported that similar incidents have occurred over the past twelve years due to pond draw downs. The NH Fish and Game Department recommended altering the draw down schedule to avoid subsequent alewife strandings.

The second incident occurred in the fall of 1995 when a private citizen reported approximately 100 dead alewives near Bay Ridge Road in Greenland. The cause of death was not identified, however, it was speculated that a short term stress from a drop in salinity caused by high freshwater inflow during the period or an isolated low dissolved oxygen condition caused the fish kill.

In October of 1997, nearly 2,400 juvenile alewives which were migrating from fresh to tidal waters were killed over a two day period by physical trauma caused by an hydroelectric turbine at the Cocheco River dam in downtown Dover. New Hampshire Fish and Game personnel reported that the mechanism that allows the fish to bypass the turbine was not operating properly. Corrective actions were initiated.

3.3.1 STATUS AND TRENDS OF SALT MARSH

Salt marshes are specialized habitats characterized by emergent vascular plants that extend within the intertidal zone from approximately mid tide height to just above the elevation of the normal spring tide line. The total area of tidal marshes within the entire state has been estimated at 7,500 acres in 1974 (3,040 ha; Breeding et al., 1974) and at 6,200 acres in 1994 (2,500 ha; USDA, 1994). The difference may not indicate an actual decline, since no significant losses in marsh acreage have been documented in ten years of 305b reports issued by NH DES. The ecology of salt marshes of the Great Bay Estuary has been reviewed by Short and Mathieson (1992), and plant species occurring in the salt marshes of New Hampshire have been listed in this (Appendix J) and earlier reports (NAI, 1988; Ward et al., 1993). The most common plant associated with the low marsh in New Hampshire is the tall form of *Spartina alterniflora* (salt marsh cordgrass); the most common high marsh species include *Spartina patens* (salt meadow cordgrass), the short form of *Spartina alterniflora, Distichlis spicata* (spike grass) and *Juncus gerardii* (black grass) (USDA, 1994). In addition, there is a list of all plant species that occur in New Hampshire wetlands (Reed, 1988).

3.3.1.1 Distribution, Standing Crop and Productivity

Salt marshes were identified and mapped for the National Wetlands Inventory (Tiner, 1984) and more recently in two studies that covered the tidal marshes of the state (NAI, 1988, Ward et al., 1993). No comparison of the inventories has been made, but the more recent work is more accurate and differences, if determined, may not actually reflect changes in salt marsh distribution. The tidal marshes within the Great Bay Estuary, including all tributaries, were mapped utilizing color infrared transparencies and extensive ground truth work (Ward et al., 1993). Based on this work, the location and areas of salt marshes and algal beds in the Great Bay Estuary were calculated by Weiss (1993). A total of 2,230 acres (9.025 km2) of tidal marsh are located in the Great Bay Estuary, with the lower Piscataqua River, the Squamscott River, and the Great Bay having the most extensive tidal marsh area. Coupled with the National Wetlands Inventory map, the Great Bay data provided the basis for another salt marsh map produced by USF&WS (Figure 3.16; Banner and Hayes, 1996).

Annual aboveground productivity of smooth cordgrass (*Spartina alterniflora*) was estimated by Chock (1975) to be approximately 604 g dry weight/m2/yr for a salt marsh at Cedar Point (Little Bay). No estimates of total annual productivity (including belowground production) have been reported for salt marshes in New Hampshire. However, some standing crop data, usually sampled during peak aerial biomass or at the end of the growing season, are available. Standing crop does not include the leaves and shoots produced that were eaten, dead, or otherwise removed over the course of the year. Peak standing crop measurements for high marshes dominated by salt meadow hay (*Spartina patens*) as well as low marsh areas of *S. alterniflora* are found in Table 3.5 and in the following references (Nelson, 1981; Short, 1987; Short and Mathieson, 1992; Burdick, 1992; Burdick and Dionne, 1994). In an examination of the relationship between above and belowground standing crop, Gross et al. (1991) report values for a high marsh dominated by short form *S. alterniflora* in Rye of 527 and 754 g dry wt/m2 of total above ground and live below ground standing crop, respectively.

Although often ignored, salt marshes can contain a significant macroalgal component. This is especially true of low marshes dominated by *S. alterniflora* occurring near extensive intertidal macroalgal beds (e.g., Little Harbor, Cutts Cove) where they may become

TABLE 3.5 *Standing crop of peak aboveground plant biomass in New Hampshire salt marshes (biomass = g dry wt/m^2).*

Site [Years of data]	Habitat (n/yr)	*S. alterniflora*	*S. patens*	Other*	Algae	Total
Little Harbour[1] [1]	Low marsh (6)	512	0	0	1020	1532
	High Marsh (6)	28	614	12	3	657
North Mill Pond[2] [3]	Low marsh (8)	683	**	14	9	70
Cutts Cove[2] [3]	Low marsh (16)	322	**	35	818	117
Great Bay NERR[3] [1]	High marsh (5)	56	311	22	0	38
Rye Harbor[3] [1]	High marsh (5)	50	293	12	0	35

*Other vascular plants, including grasses and fortes, e.g., *Salicornia europaea.*

** *Spartina patens* was the predominant species in this category, but was lumped with Other.

1 = Burdick 1994, 2 = Burdick and Short 1997, 3 = Burdick, unpublished data

heavily colonized by fucoid algae with distinctive growth forms, called marsh ecads (*Ascophyllum nodosum* variety *scorpioides* and *Fucus vesiculosus* variety *spiralis*; Norton and Mathieson, 1983). In a study of seasonal trends in the standing crop of *S. alterniflora*, the associated ecads of fucoid algae were also assessed by Chock (1975), who concluded they contributed greatly to marsh productivity. A later study of eight coastal salt marshes near the mouth of the Piscataqua River found fucoid biomass ranged from 100 to over 1300 g dry weight per m2 with the algae averaging almost 60% of the total plant biomass found in the low marshes (Burdick, 1994).

3.3.1.2 Habitat Impacts and Losses

Threats to salt marshes in New Hampshire have been reviewed and summarized (USDA, 1994). Specific threats and impacts to marshes were categorized by human activities that are considered to be important. Currently, marine development poses the greatest threat to salt marshes through dredging, dock construction, shoreline development along the upper marsh edge, and development across marshes that result in tidal restrictions. Other potentially important impacts to marsh function include harvesting marsh resources and conflicting uses within these habitats.

Dredging Impacts and Harvesting Effects

Dredge and fill operations have altered marshes within all of the seacoast estuaries to some extent. Large areas of the Hampton-Seabrook marsh were dredged and filled for residential housing. Rye Harbor has been dredged on several occasions, and in 1941 and 1962 the spoil was placed on the salt marsh landward of the harbor. This transformed several acres of marsh into upland habitat and has negatively impacted over 10 additional acres. The ecological impacts at the sites of sediment dredging have not been assessed, but impacts to the marsh from disposal were reviewed by Burdick (1992). Elevating the surface and surrounding the area with earthen dikes severely reduced salt water flooding and increased fresh water flooding in the spring. These changes lowered soil salinity, led to the displacement of native marsh plants by *Phragmites*, *Typha* and upland plants, resulted in the formation of die-back areas and large pools of water, and caused a direct loss of fish habitat.

In addition to direct negative impacts, dredging may reduce sediment sources to marshes, leading to an inadequate sediment supply to support marsh maintenance and development. Dredging may also increase the wave energy environment, leading to increased ero-

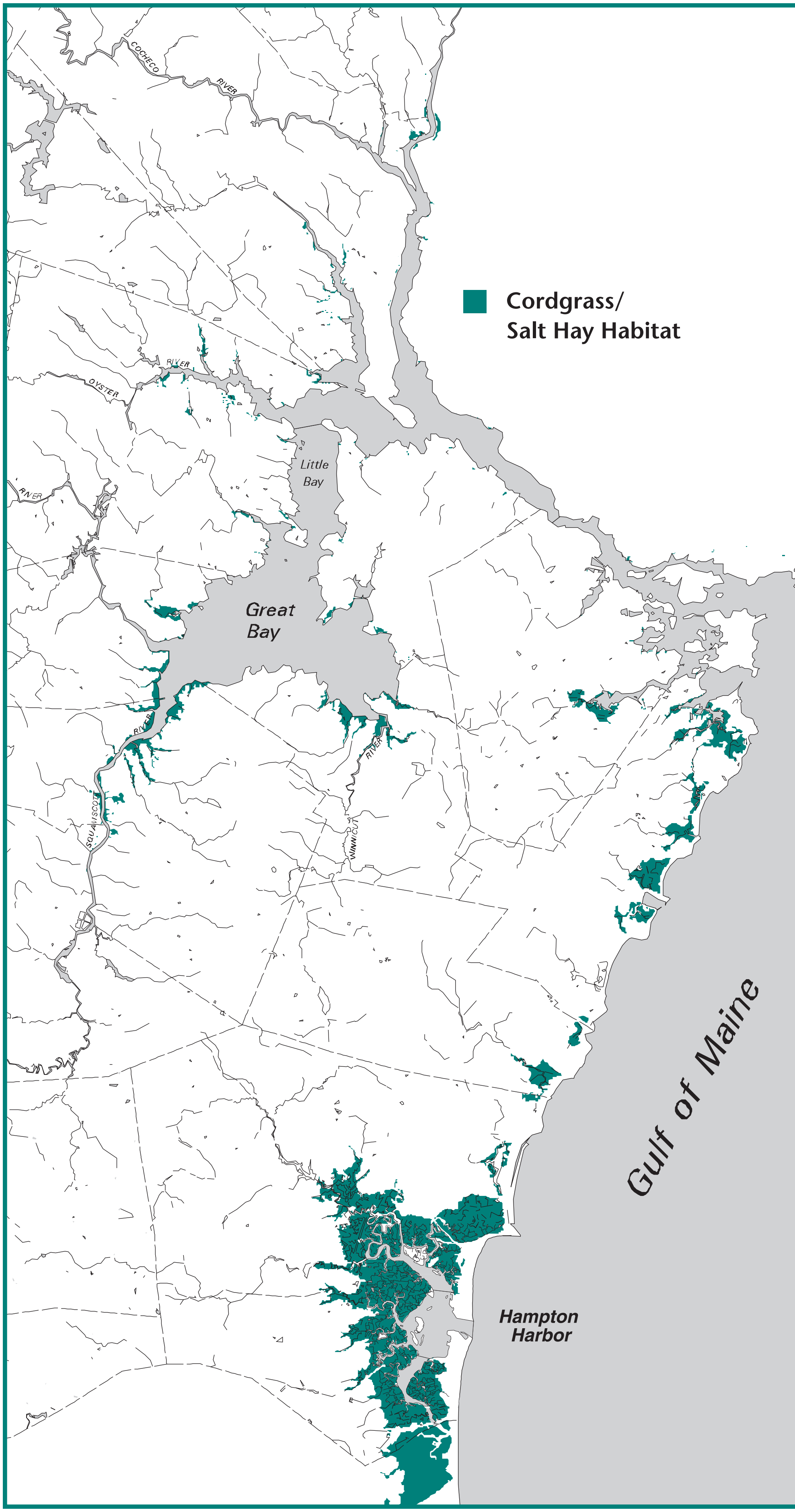


FIGURE 3.16

Habitat map for cordgrass/salt hay. From Banner and Hayes (1996).

sion at the seaward edge of marshes. On the other hand, increased sediment supply or a reduced wave environment from dredging may allow the expansion of a marsh at its seaward edge.

Although salt hay was harvested widely along the New Hampshire seacoast from the 17th to 20th centuries, the intensity of marsh management to improve yields and harvesting efficiency are poorly known (Breeding et al., 1974). Ditching to improve hay yields (not equivalent to mosquito ditching) was routine. Salt hay farming continues to this day and has experienced a small revival in northern Massachusetts, yet the impacts from salt hay farming on salt marsh ecosystems are unknown (Rozsa, 1995).

Impacts from Docks, Piers and Shoreline Development

Impacts from docks and piers on salt marshes have not been assessed in New Hampshire. Clearly, solid fill and crib structures built on marshes eliminates them and are discouraged, but open piers have also been shown to reduce productivity and viability of salt marshes in other New England States (Michael Ludwig, NMFS Milford, CT). The US ACOE has issued design guidelines for structures over marshes (height over sediment needs to be at least as great as width of the structure), but it is not clear whether such guidelines prevent degradation, nor have the dock impacts to marshes been assessed quantitatively and systematically.

Similar to docks, impacts from other forms of shoreline development are severe when structures are built upon and over marshes. However, structures placed at the landward edge of salt marshes can also have serious effects on marsh viability and maintaining these habitats in the near future (Pethick, 1983). Because sea level is rising, and marshes have traditionally migrated landward as well as built vertically to maintain themselves in the face of rising sea level (Redfield, 1965), increased local sea level is expected to be accompanied by landward migration of salt marshes. However, structures placed at the landward edge of salt marshes will prevent these habitats from migrating landward with local sea level rise (Pethick, 1983). Furthermore, the rate of sea level rise is expected to increase in New Hampshire from 1.2 to 7.5 mm/year. Structures that prevent marshes from migrating landward will result in marshes becoming narrow and lower in elevation. In time, waves reflecting from submerging marshes will erode the marsh peat and exacerbate local erosion and flooding problems (Smith et al., 1978).

Impacts from Tidal Restrictions

Tidal restrictions influencing estuarine circulation and other functions relating to water quality that have been caused by roads, railways, dikes and causeways have severe long-term impacts to salt marshes. Construction in the intertidal and subtidal areas of an estuary always influences circulation patterns to some extent (Miller and Valle-Levinson, 1996), but linear features built on or along salt marshes that restrict tidal flow have significant impacts (Marrone, 1990). Besides altering circulation, these structures reduce flooding by salt water and tend to retain fresh water (especially in the spring), and can ultimately result in a non-tidal freshwater marsh.

Restrictions to tidal flow in salt marshes lead to areal (if habitat becomes non-tidal) as well as functional losses. In New Hampshire, significant tidal restrictions have been fully documented (USDA, 1994) and there are indications that some marshes are deteriorating. Deterioration includes replacement of emergent salt marsh vegetation by open water, unvegetated flats, freshwater plant species or invasive species such as purple loosestrife and common reed. Marsh deterioration is a symptom of changes in local processes with the result that the marsh is unable to maintain itself. Besides reducing or even excluding fish access to their habitat (Burdick et al., 1997), tidal restrictions appear to lead to declines in productivity and habitat value for wildlife.

Impacts to water quality and soil chemistry from tidal restrictions are not well known, but serious negative impacts to water quality have been documented elsewhere (Portnoy, 1991). In New Hampshire, current knowledge is limited to soil and creek salinity, soil redox potential, soil moisture and soil organic matter (Short, 1984; Burdick, 1992; Burdick and Dionne, 1994; Ammann unpublished data; Burdick et al., 1997; unpublished data).

Salinity changes are the most obvious impacts, with restrictions generally leading to freshening of the marshes when compared to control marshes or the same marshes following restoration of tidal exchange (Table 3.6). Reductions in salt water flooding to restricted marshes allows for chemical and microbial oxidation of reduced soil constituents, leading to higher, more positive redox potentials, loss of soil organic matter, and lower pH (Burdick and Dionne, 1994). Furthermore, the ability of the marshes to remove suspended sediments from tidal waters is certainly curtailed by tidal restrictions, though these impacts from restrictions have not yet been quantified.

3.3.1.3 Habitat Change Analysis and Modeling

Large areas of salt marsh have been filled for residential and industrial development (Breeding et al., 1974) while other areas are deteriorating due to tidal restrictions commonly associated with roads. It is estimated that New Hampshire still has 50% of its 18th Century tidal wetlands and 90% of its 18th Century non-tidal wetlands (NHDES, 1996b). More recent data summarizing impacts of permitted projects and known violations on tidal and non-tidal wetlands are contained in the bi-annual 305(b) reports sent to Congress by NHDES. There has been very little net loss of tidal wetlands in the past 10 years (Table 3.7). The data indicate small losses have occurred in non-tidal wetland acreage statewide, although the most recent report states that "...there has been no measurable net loss of wetlands functional value" (NHDES, 1996b). Natural gains in wetlands through the activities of beaver as they dam creeks and flood forests is esti-

Soil salinity changes in salt marshes from hydrologic manipulations. **TABLE 3.6**

		Soil Salinity			
Estuary/Marsh name	**Type of Restriction**	Before Restriction	After Restriction	After Restoration	Reference marsh
Hampton Estuary					
Drakeside Rd Marsh[1]	Undersized Culvert	—	8.5	10.1	10.5
Rye Harbor					
Awcomin Marsh[2]	Diked dredge fill	—	6.5	21.6	24
Locke Road Marsh[3]	Undersized Culvert	—	16.4-27.0	NA	23.1
Great Bay Estuary					
Peverly Ponds[4] (GBNWR)	Causeway with Tidal Gate	—	NA	NA	
Sandy Point Marsh[1] (GBNERR)	Berm formed by debris	—	5.6	25.1	25.2
Mill Brook Marsh[5] (Stuart Farm)	Causeway with Tidal Gate	—	0.0	19.5	16.2

Approximately 50 other sites in New Hampshire are hydraulically restricted as determined by the NRCS (USDA 1994), but no data on soil chemistry at other sites is available at this time.

1 Burdick, Unpublished data
2 Burdick and Dionne, 1994
3 Little, Unpublished data
4 USF&W Service, Data unavailable at this time
5 Burdick et al. 1997

TABLE 3.7 *Impacts of permitted projects and known violations on state-wide wetlands: 1988-1996. Data from NHDES (1996).*

	Tidal Wetlands (acres)		Non-tidal Wetlands (acres)	
Year	Impacted	Total	Impacted	Total
1987-88	0	7,500	25-50	95,000
1989-90	0	7,500	50	200,000
1991-92	0	7,500	150	192,500
1993-94	0	7,500	200-300	400,000-600,000
1995-96	0	7,500	150-250	400,000-600,000

mated to be in the tens of acres each year (NHDES, 1989a).

Specific restrictions causing deterioration of the salt marshes have been enumerated for the tidal wetlands of New Hampshire by the Natural Resource Conservation Service (USDA, 1994). They found 50 tidal restrictions in the state which encompass over 20% of the salt marsh area remaining in NH (1,300 out of 6,200 acres; USDA, 1994). The report shows that marshes deteriorating from tidal restrictions are more commonly found at the upland borders of large marsh systems (i.e., Hampton/Seabrook Estuary) and behind smaller barrier beach systems (i.e., Little River Marsh), but are spread throughout the state. As discussed previously, deterioration includes losses in salt marsh acreage as well as functional losses. Thus in contrast to the 305(b) reports (NHDES, 1996b), it appears that indirect losses of tidal wetland acreage as well as functions continue to occur. However, restoration of tidal exchange to some sites may be able to reverse some of these wetland losses (see restoration section).

Preliminary results of change analyses based on aerial photography of selected marshes in the tidal reaches of the Squamscott River indicated some increase in open water (salt pannes) in several marshes (Ward, in preparation).

The development and evolution of salt marshes in New Hampshire is thought to follow the widely held model developed in Massachusetts by Redfield in 1965, later verified by Keene (1980) in a Hampton marsh, and recently verified and modified for salt marshes in Maine by Kelley et al. (1995). Modern marshes began developing about 4,000 years ago when sea level rise slowed and low marshes became established on intertidal sediments. The low marshes expanded seaward and at the same time collected sediments to build vertically and become high marsh. The high marsh, in turn, expanded seaward following the expansion of low marsh and landward covering upland as sea level slowly continued to rise, resulting in the flat, high marsh habitat that is typical of New Hampshire salt marshes.

A conceptual model of the changes in marshes due to impacts from tidal restrictions has recently been proposed by Burdick et al. (1997), but estimation of rates within the model for simulating changes in tidally-restricted and restored marshes have not been made or verified. Furthermore, few of the marsh functions that are responsible for socially-esteemed values have been quantified. Increases in our understanding of habitat functions and change will support modeling and improve marsh management.

3.3.2 STATUS AND TRENDS OF MACROALGAE

3.3.2.1 Distribution, Standing Crop and Productivity

Macroalgal habitats are best characterized as those where seaweeds are found growing on rocky shorelines and into the subtidal zone to depths where the seaweeds, being light dependent, remain in the photic zone. Seaweeds also form important ecological components of salt marshes, seagrass beds, mudflats, channels, and artificial substrata such as pilings and rip-rap, but the focus in this report is on the rocky shorelines and channels dominated by seaweeds. There are a total of 219 seaweed species known from New Hampshire (Appendix J; Mathieson and Hehre, 1986; Mathieson and Penniman, 1991). In these reports, large-scale spatial and seasonal distributions are reported for many algal species and the factors that control the distributions are discussed. For example, some species were found to occur in Great Bay but not on the open Atlantic Ocean. Distribution maps showing species occurrences at specific sites were compiled from these earlier works by Banner and Hayes (1996) for knotted wrack (*Ascophyllum nodosum*), Irish moss (*Chondrus crispus*) and tufted red weed (*Macrocarpus stellatus*) (Figures 3.17; Banner and Hayes, 1996). At specific sites, changes in algal communities have been documented (e.g., Dover Point by Reynolds and Mathieson, 1975), and the potential for revisiting other previously sampled sites is very good. However, long term changes in algal distributions over time are not currently available.

A detailed study of the occurrence and standing crop of algal species along the shores of the Oyster River and its tributaries was conducted in 1993 (Mathieson, unpublished data). *Enteromorpha prolifera, Ulva lactuca, Ascophyllum nodosum* and *Fucus vesiculosus* were common to virtually all areas. The occurrance of *Polysiphonia harveyi, Ulva oxysperma, Chondrus crispus, Gracilaria tikvahiae* and unidentified cyanobacteria were also measured in a few tributaries. The location of the algae with respect to elevation within the intertidal zone was also noted.

Standing crop and growth estimates have been made for a few species of red and brown algae and these reports characterize the habitats as well (Mathieson and Burns 1975; Chock and Mathieson 1976; Mathieson et al. 1976; Josselyn and Mathieson, 1978). In 1993, a minor survey of algal species that estimated standing crop by species was conducted by Mathieson at Adams Point and reported in Langan and Jones (1993). Paired replicate clip plots at top, middle, and lower intertidal zones showed the dominance of the brown fucoid algae, *Ascophyllum nodosum*, with important contributions in the middle and lower zones by both red and green species.

3.3.2.2 Habitat Impacts and Losses

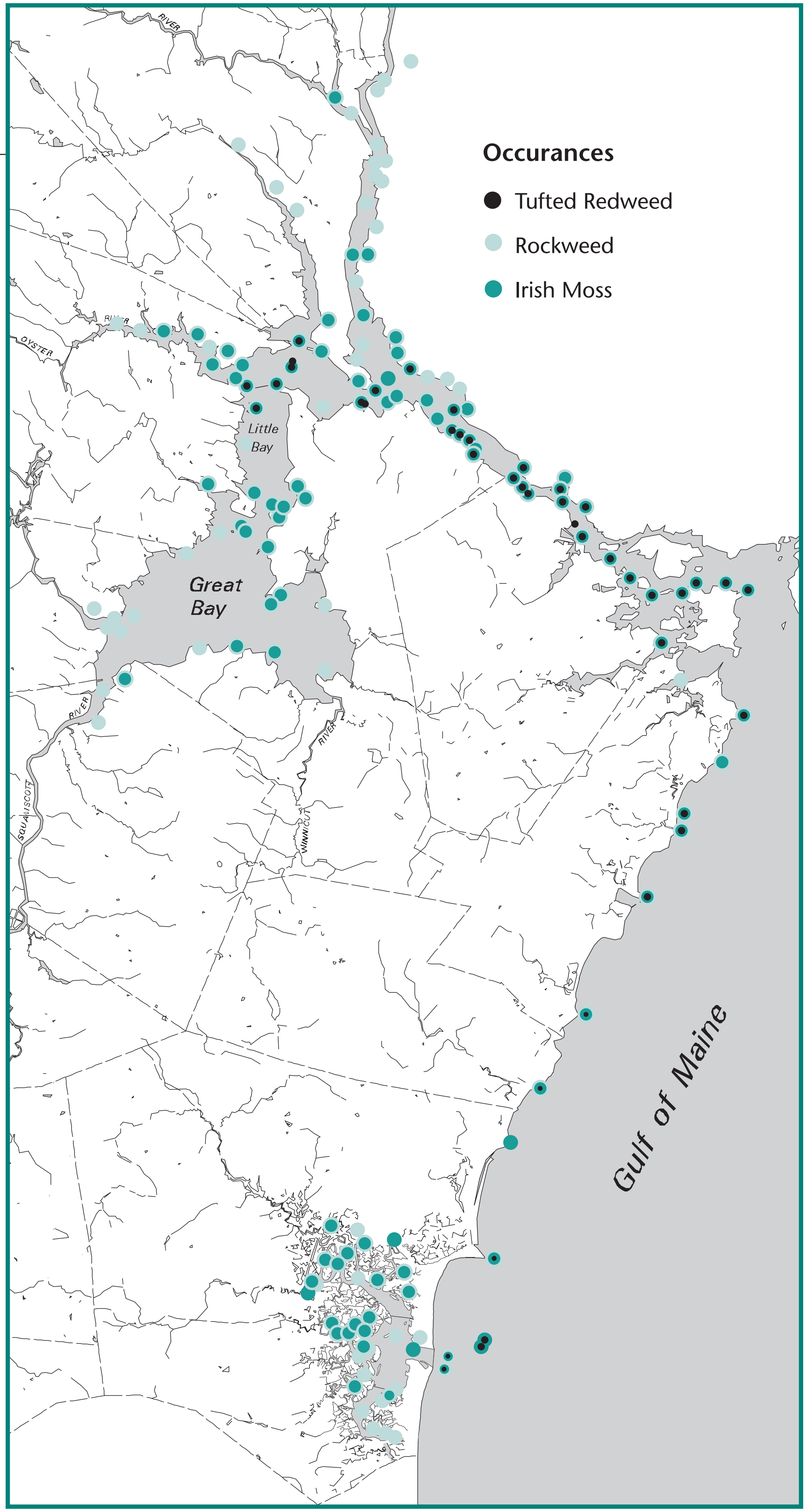
Channel work in the lower Piscataqua River has occurred on many occasions, and included blasting ledges, dredging in the river, as well as in Little Harbor at the turn of the century. Few studies are available that document impacts to intertidal and subtidal plant habitats, and impacts to benthic communities have been regarded as minor in the past (i.e., Brown and Fleming 1989). Dredging not only directly removes algal habitat, it reduces algal production and survival because suspended sediments from the dredging attenuates light needed for growth. Furthermore, the hard clean surfaces needed as sporelings attachment points become unsuitable for macroalgal recruitment after dredging activities cover them with fine sediments.

Shoreline development typically removes or buries algal beds in the intertidal zone. The extent of these impacts along our coasts has not been determined. However, placement of hard surfaces at these sites can often lead to new algal beds if algae can colonize the new surfaces (e.g., bridge abutments, rip-rap walls).

Algae has been harvested for various uses in New England, but such harvest in New Hampshire estuaries is poorly known and probably minimal. Algin and carrageenan are extracted from kelps, knotted wrack (*Ascophyllum nodosum*) and Irish moss (*Chondrus crispus*) and are used as additives in the food industry. Few algae are consumed directly in this country, but dulse (*Rhodymenia palmata*) and nori (*Porphyra sp.*) are harvested for consumption. Knotted wrack is also used for packing material to preserve live shellfish and worms. Impacts to the algal resources from experimental harvesting have been assessed for the red algae Irish moss (Mathieson and

FIGURE 3.17

Habitat map for rockweed, Irish moss and tufted redweed. From Banner and Hayes (1996).



Burns 1975). They found that plants could recover in a year after carefully controlled harvesting, but winter harvesting had greater impacts and overharvesting could cause demise of the algal beds.

3.3.2.3 Habitat Change Analysis and Modeling

What little is known about habitat change regarding the macroalgal beds of New Hampshire estuaries includes studies on the destruction of estuarine and near shore populations of kelp by a small species of estuarine snail, *Lacuna vincta* (Fralick et al., 1974). The standing crop and assemblage of algal species may be used as an indicator of nutrient status of specific sections of estuaries. Nutrient poor areas support slow-growing long-lived species whereas over-enriched areas become less diverse and dominated by opportunistic species indicative of poor habitat health. Although no synthesis currently exists, analysis of existing data and revisiting sites sampled 20 years ago could provide interesting information on the status and trends of estuarine health in New Hampshire.

The use of models to describe changes in algal beds has received little attention. In 1978, Josselyn and Mathieson (1978) created a model to describe seasonal changes in living biomass, dead biomass found on the strand line as wrack, and decomposition of wrack for fucoid algae and eelgrass within Great and Little Bays.

3.3.3 STATUS AND TRENDS OF EELGRASS BEDS

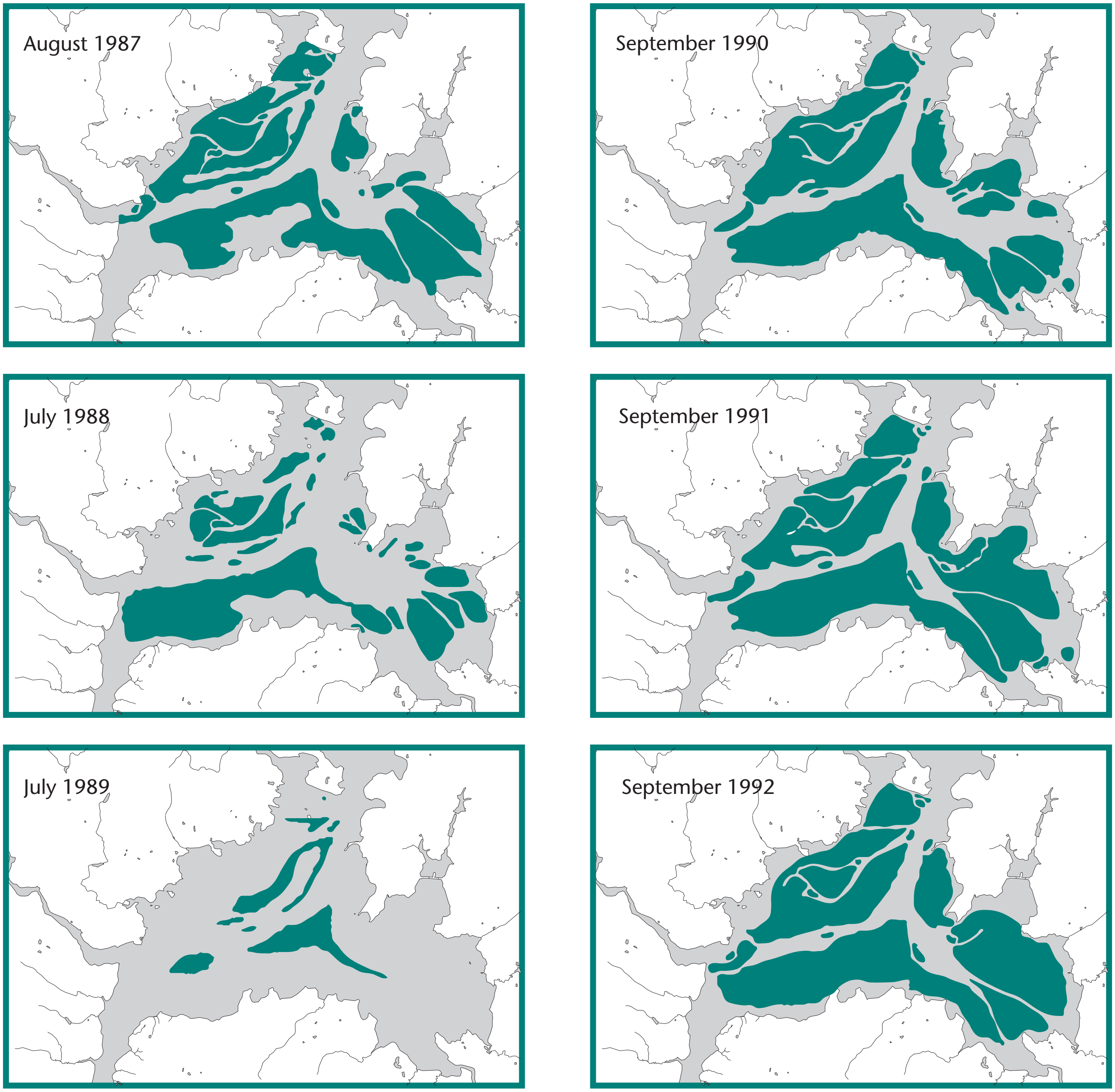
Eelgrass habitat provides the largest spatial distribution of any habitat within Great Bay (Short et al., 1992; Short and Mathieson, 1992). Eelgrass beds in the estuary occur as large meadows and small contiguous beds forming intertidal and subtidal seagrass habitats. Eelgrass habitat functions as breeding and nursery grounds for the reproduction of finfish, shellfish, and other invertebrates. Eelgrass meadows serve as a feeding area for many fish, invertebrates and birds. Additionally, eelgrass may act as a filter of nutrients, suspended sediments, and contaminants to the waters of the estuary.

3.3.3.1 Distribution, Standing Crop and Productivity

Distribution maps of eelgrass are available for most of the Great Bay Estuary for the mid-1980s (Short et al., 1986) for Great and Little bays through the 1990s (Short, unpublished) and for the mouth of Little Harbor in 1996 (Short, 1996). Most eelgrass habitat in New Hampshire has been surveyed within the last six years; however, a comprehensive map of these findings has not been compiled. A GIS layer of eelgrass habitat has recently been completed by the U.S. Fish and Wildlife Gulf of Maine Project (Banner and Hayes, 1996).

Eelgrass in the Great Bay Estuary has experienced fairly dramatic changes in population distribution and total productivity over the last two decades. Spatial and temporal changes in eelgrass populations prior to 1991 have been reported in numerous publications (Short et al., 1986; Short and Mathieson, 1992; Short et al., 1992; Short et al., 1993; Burdick and Short, 1995) and these data are shown in Figure 3.18. The Great Bay Estuary suffered from a decline in eelgrass populations during the 1980s resulting in a low point of eelgrass distribution in 1989. These decreases in population represent dramatic losses of eelgrass habitat as a result of wasting disease (Short and Mathieson, 1992). Similar problems and trends in eelgrass populations have been reported for the neighboring Annisquam Estuary at Cape Ann in Massachusetts (Dexter, 1985). The period of eelgrass decline in Great Bay was followed by rapid recovery where extensive seed production led to extensive revegetation within Great Bay proper. This recovery can be seen by comparing Figures 3.19 and 3.20. In contrast, some beds in Little Bay and along the Piscataqua River have not reappeared and efforts are underway to protect remaining beds from development and restore significant beds to these portions of the estuary.

FIGURE 3.18 *Time series of eelgrass distribution in Great Bay.*



Standing crop and other population characteristics of the eelgrass population near the red nun buoy at the mouth of Great Bay were made in 1987, 1989 and 1993 (Table 3.8; Langan and Jones, 1993). Both shoot and total (shoots, roots and rhizomes) standing crop data show increases between 1987 and 1993, the period when eelgrass was declining and then recovering from episodes of wasting disease. The Wasting Disease Index was measured for each year and showed the greatest levels of disease occurred in 1989, the year that most of the beds in Great Bay had succumbed to the disease (Short et al., 1993).

3.3.3.2 Habitat Impacts and Losses

Dredging Impacts on Benthic Habitats and Sediments

As previously mentioned, creation and maintenance of navigable channels in the Great Bay Estuary has occurred for

Population characteristics of eelgrass in the small beds at the mouth of Great Bay (near the red nun buoy): August 1987, 1989, 1993. **TABLE 3.8**

Year	Shoot Density #/m²	Rhizome Length cm/m²	Eelgrass Biomass grams dry wt./m² Shoots	R&R	Total	Algal Biomass g/m²	Morphology Length cm	Width mm	Leaves #/shoot	Wasting Disease Index %
1987	427		197	66	263		114	5.0	4.7	16.6
1989	504		249	128	377		125	5.2	4.8	43.5
1993	426	139	395	59	454	25	145	4.9	3.8	10.0

many years, though little information exists that describes impacts to eelgrass beds. In 1992, the threat to an eelgrass bed from dredging and constructing the new Port of New Hampshire pier facility was recognized as a serious ecological impact which required habitat mitigation. As a result, seven acres of eelgrass were transplanted into various sites within the estuary. A proposed dredging at the mouth of Little Harbor to deepen mooring areas may impact some of the twenty five acres of eelgrass beds.

Impacts of Boating, Docks, and Piers

In general, commercial boat operators have had little impact on submerged hazards, including submerged vegetation. However, recreational boaters are often unfamiliar with such hazards and have often been observed entangled in eelgrass or grounded on the shallow flats of eelgrass beds in Great Bay (Burdick, personal observation). Further evidence of boat damage in Great Bay includes boat scarring from propellers and damage from hulls during groundings, but the damage appears to be minor and the beds have rapidly revegetated (Burdick, personal observation). Continued recreational boat use in the estuary will pose continued risks to eelgrass meadows.

Because docks and piers cross shallow subtidal habitats to secure vessels in deeper waters, it is likely that these structures have crossed and impacted eelgrass beds and other habitats (Burdick and Short, 1995). However, no record remains for whatever impacts have occurred over the past three centuries from these structures. Currently, few docks appear to influence eelgrass beds. The large commercial dock being built for the expansion of the Port of New Hampshire will have significant impacts (see habitat mitigation section below) that is being assessed.

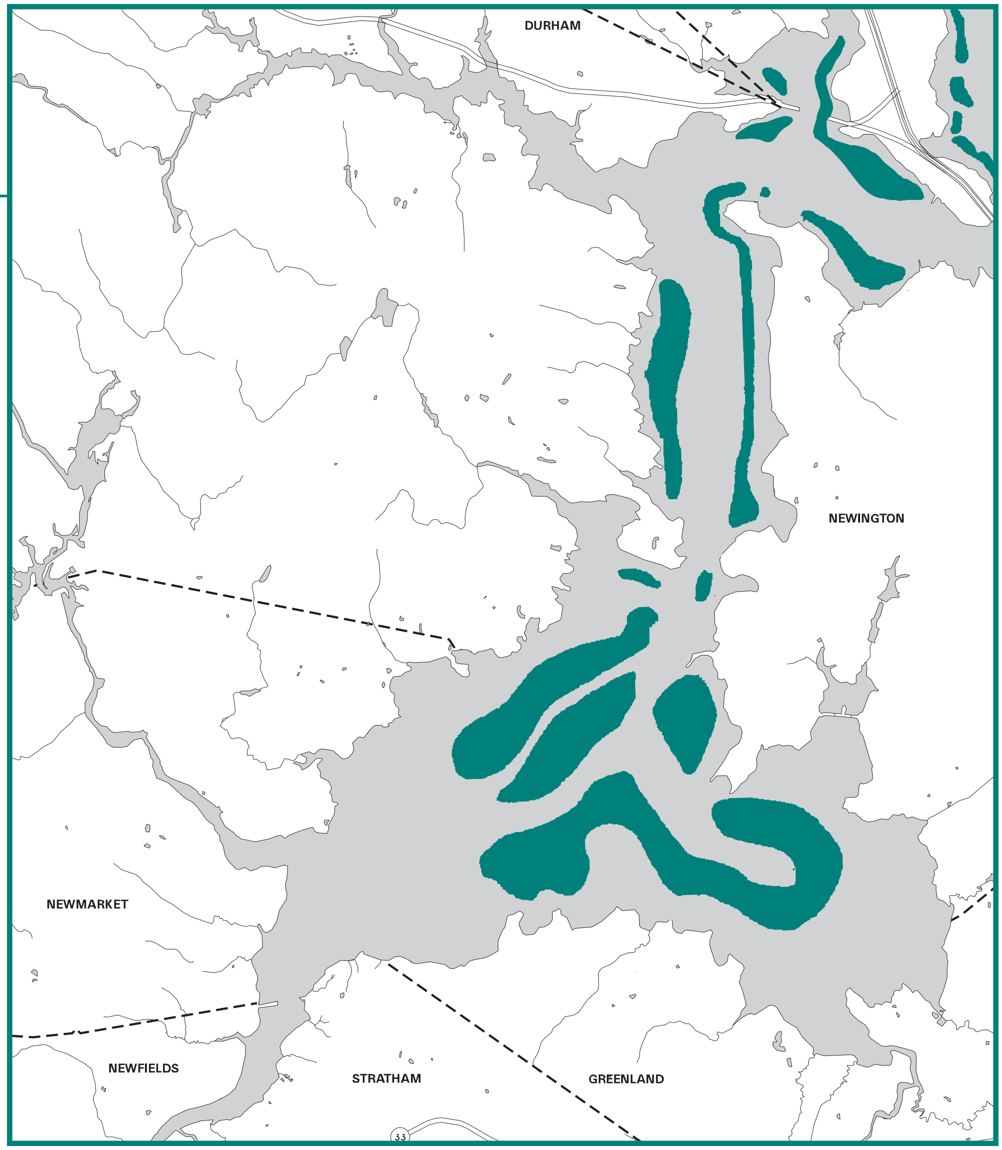
Impacts from Shoreline Development and Harvesting

Human development of the shoreline around Portsmouth Harbor, including the Portsmouth Naval Shipyard, has filled many acres of shallow estuarine habitat that was at least partly occupied by seagrass beds and salt marshes. Specific instances include the expansion of the Shipyard in the 20th century which connected several islands and most recently included filling marshes and mudflats for the Jamaica Island Landfill in the 1970s (Johnston et al., 1994). Similarly, development of transportation and marine facilities around Noble's Island resulted in filling of North Mill Pond and Cutts Cove. Bridges and causeways across river channels, bays and inlets as well as salt marshes have also probably led to the destruction of many seagrass beds and marshes along the seacoast. Shoreline development for marine related uses continues to impact marshes eelgrass beds today. For example, potential impacts from the Port of New Hampshire expansion are outlined in the mitigation plan (Short et al., 1992), which identifies specific eelgrass beds, mud flats and salt marshes as three estuarine habitats that may be impacted from port expansion (see habitat mitigation section below).

Anthropogenic inputs of contaminants to the estuary resulting from devel-

FIGURE 3.19

Eelgrass distribution in Great Bay and Little Bay: 1981.



opment within the watershed may have significant indirect impacts on eelgrass habitat. Potential impacts were outlined for Great Bay Estuary (Short, 1992), and have been documented in other New England estuaries (Short et al., 1995; Short and Burdick, 1996). They include eelgrass loss from nutrient over-enrichment and increased sediment input. The primary cause of these eelgrass losses is reduction in water clarity, a result of human impacts to the estuarine watershed. Anthropogenic impacts to eelgrass habitat within the Great Bay Estuary have not been documented.

Seagrass has been harvested in the northeast for building insulation, upholstery stuffing, but is probably most widely used for garden mulch and fertilizer. The scale of such activities in New Hampshire do not appear to have been large, and although their potential impacts are unknown, they are likely minor.

3.3.3.3 Habitat Change Analysis and Modeling

The spatial distribution of eelgrass habitat in Great Bay has been modeled using a spatial grid modeling structure (Short et al., 1996). The model calculates and predicts the changes in eelgrass habitat that result from poor water quality and wasting disease activity (Short et al., 1986; 1995) after incorporating tidal flows with distributions of water quality characteristics available from throughout the Great Bay Estuary (Jones and Langan, 1994a). Eelgrass habitat modeling in the Great Bay Estuary is now limited by the lack of

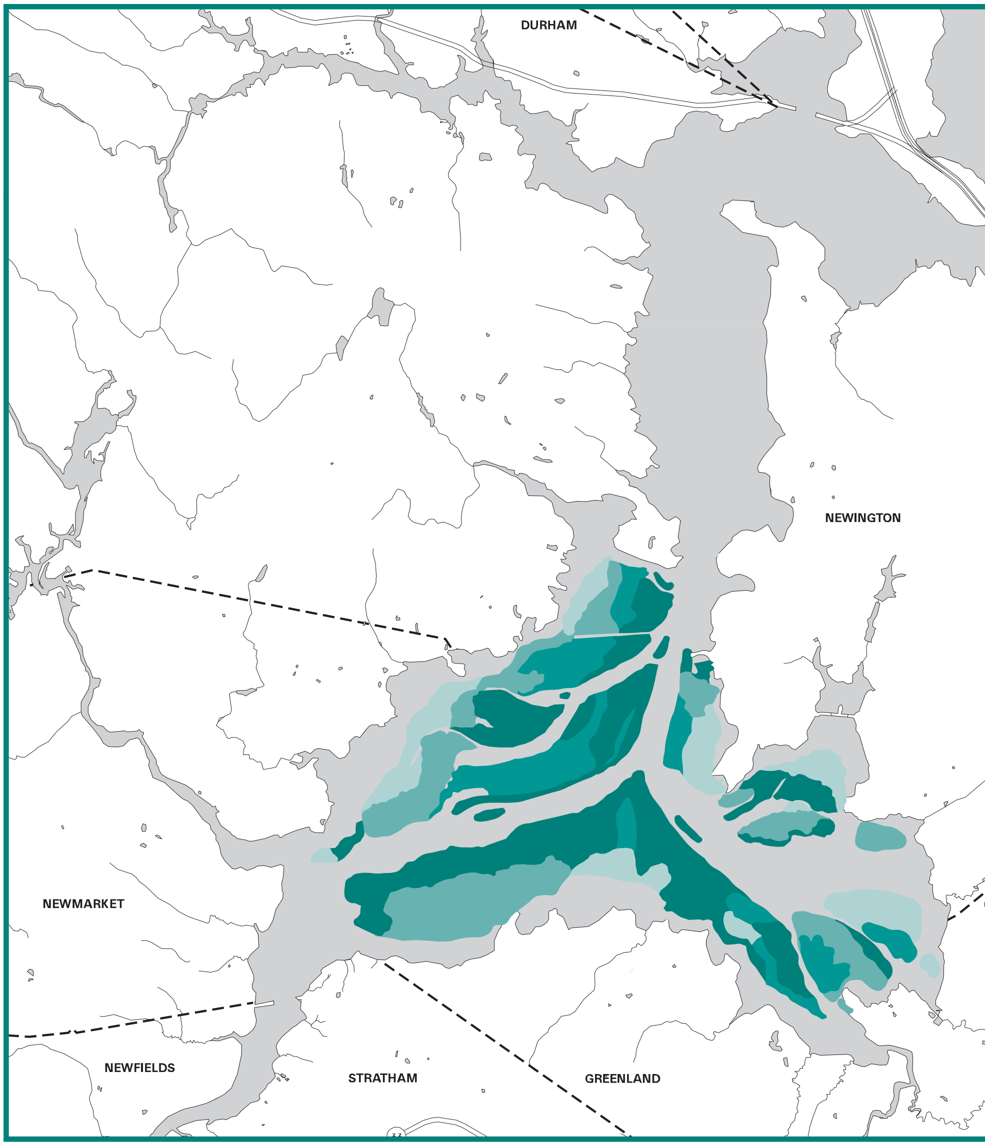


FIGURE 3.20

Eelgrass distribution and density in Great Bay and Little Bay: 1990.

adequate hydrodynamic information to fully implement the spatial distribution model. With such information, the model will continue to improve and become a useful predictor of eelgrass habitat distribution. This management tool can then be expanded to incorporate other estuarine habitats, including salt marsh, algal beds, and shellfish areas.

Change analysis of eelgrass distribution in the Great Bay Estuary has provided valuable information for understanding the dynamics of the eelgrass habitat. A loss of eelgrass distribution in Great Bay was documented between 1981 and 1984 for Great Bay, Little Bay and the upper Piscataqua River (Short et al., 1986). The dramatic losses of eelgrass over this time period signalled a recurrence of the wasting disease. This disease devastated eelgrass populations in the 1930s along both coasts of the North Atlantic (Short et al., 1988). The wasting disease was subsequently shown to result from a pathogenic infection of eelgrass populations by a marine slime mold *Labryrinthula zosterae* (Short et al., 1987; Muehlstein et al., 1991).

More recent change analysis in Great Bay has documented further loss of eelgrass through the remainder of the 1980s (Figure 3.18) to a low point in eelgrass distribution in July, 1989. This dramatic decline in eelgrass was followed by an equally dramatic increase and recovery of eelgrass beds that occurred between 1989 and 1990 (Burdick et al. 1993). The loss during the 1980s was determined to be caused by rapid infection and spread of *Labryrinthula zosterae*. The spread of the disease ceased in late 1988 following a rainfall event which decreased the salinity of the estuary and inhibited the growth of the pathogen. The recovery of eelgrass during 1989 through 1990 was the result of high levels of sexual reproduction and seed dispersal within the estuary producing extensive revegetation of mudflat areas by eelgrass seedlings.

The total area of eelgrass loss in Great Bay between 1986 and 1989 was 690 hectares (ha) and the area of recovery from 1989 to 1990 was 700 ha. This change analysis suggests that the loss of area was extremely rapid at 230 ha/y but that the recovery through seedling recruitment was even greater, over 600 ha/y. The rapid recovery due to recruitment of new shoots from seeds had actually begun in 1989, but did not show until the 1990 aerial photographs. The 1992 maps indicate more extensive eelgrass cover in Great Bay than was reported by Nelson (1981) (Figures 3.19 and 3.20).

As of 1990, distribution of eelgrass in Little Bay was approximately 2% (Figure 3.20) of what was reported in Little Bay in 1981 (Figure 3.19; Nelson 1981), however the source of the data and the methods used by Nelson (1981) are unclear. The most recent published map of eelgrass in Little Bay (Burdick et al. 1993) includes a persistent bed off Dover Point and a small bed just west of the General Sullivan Bridge in Newington. A decade prior to these observations, Nelson (1981) reported eelgrass along both sides of Little Bay and extending into the Bellamy River. Little Bay has been monitored annually from 1984 to the present, and no new patches of eelgrass were found prior to 1993. Since 1993, natural recruitment of new eelgrass beds has occurred at 3 sites in Little Bay. The loss in area of eelgrass in Little Bay from 218 ha in 1981 (Nelson 1981) to 3.7 ha in 1990 (Burdick et al. 1993) shows a loss of 98% of the eelgrass in Little Bay over that 9 year period. The increase from 1993 to the present has not been quantified. In 1997, an effort was begun to restore eelgrass to parts of Little Bay (see section on Habitat Restoration).

In the Piscataqua River, eelgrass is currently found in small beds along the shoreline in many areas. On the Maine side of the Piscataqua River, the most extensive bed of eelgrass exists off Addlington Creek just south of the confluence of Little Bay and the upper Piscataqua River. Small patches of eelgrass are found further down the Piscataqua River on the Maine side and adjacent to the small boat passage under the Memorial Bridge. On the New Hampshire side of the river, eelgrass is found in Outer Cutts Cove adjacent to the New Hampshire Port Authority construction and at several sites along the Piscataqua south of Dover Point where eelgrass restoration has taken place as part of the New Hampshire eelgrass mitigation project (Short et al., 1996; Davis and Short, 1997).

Using the 1981 NH Fish and Game map of eelgrass distribution in the Piscataqua River as a baseline, (Nelson, 1981) data from 1990 (Burdick et al., 1993) indicate that there was a loss of approximately 50 ha of eelgrass in a ten year period. The restoration of 3.5 acres of eelgrass habitat along the New Hampshire side of the Piscataqua River (Short et al., 1996) has increased the area of eelgrass in the river, however changes in the existing eelgrass areas from 1990 to 1997 have not been documented. In Portsmouth Harbor, eelgrass has not been carefully mapped and no historical data has been reported, but observations of eelgrass beds over the past decade suggest fairly consistent distribution (Short, 1992; Johnston et al., 1994) . Eelgrass has been found throughout many parts of Portsmouth Harbor with extensive beds at the mouth of the Harbor on both the New Hampshire and Maine side. At these sites, eelgrass grows to a maximum depth of 11 meters as a result of clear water from the Gulf of Maine entering the River. More comprehensive mapping of eelgrass distribution in the entire Great Bay Estuary is needed to establish baseline conditions for future habitat monitoring and change analyses.

Because of the diversity of habitats, New Hampshire's estuaries support an impressive array of living resources. In addition to the species described above, terrestrial wildlife, birds and marine mammals are also present. Mammals living within the Great Bay area include whitetail deer, beaver, red fox, mink, otter, muskrat, coyote and raccoon. In addition, Great Bay is part of the Atlantic flyway and an important migratory stopover as well as wintering area for many birds. As a result, there are substantial populations of both seasonal and year round birds that undoubtedly have a direct affect on water quality throughout the coastal zone.

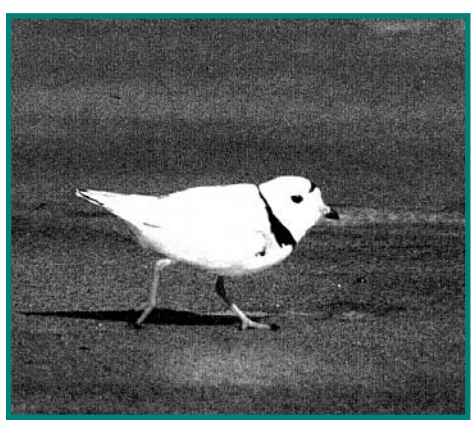
3.4.1 MARINE MAMMALS

Harbor seals (*Phoca vitulina*) may be found throughout the Great Bay Estuary, and are common in the lower portions of the estuary as well as in Rye Harbor and Hampton Harbor. A hooded seal was seen in Little Bay in 1998. Harbor porpoises (*Phocoena phocoena*) frequent the lower portions of the estuary and have been sighted in Little Bay. It is likely that some whales find their way into Portsmouth Harbor (e.g., a humpback whale, *Megaptera novaeangliae* sp. travelled up the Piscatatqua River to the mouth of Little Bay in 1995). There are also maps for sightings of 5 whale species in the Gulf of Maine that include sightings off the coast of New Hampshire (CeTAP, 1982 in NAI, 1994). Harbor seals (*Phoca vitalina*) were the only marine mammal observed in a study where weekly observations were made for 12 months during 1980-81 throughout the GBE (Nelson, 1982). Seals were sighted from November through April, most often during March and April. They were sighted most often in Little Bay, with infrequent sightings in Great Bay and the Piscataqua River. Data maintained by NOAA/NMFS indicates an increase in harbor seal populations throughout the New England region, confirming observations by local fishermen as well as impingement data from the Seabrook Station Environmental Studies (NAI, 1996).

3.4.2 WATERFOWL AND SHOREBIRDS

The Seacoast area is the principal wintering waterfowl location in New Hampshire (Vogel, 1995), with 75% of the wintering waterfowl in Great Bay. A recent mid-winter survey of mallards, black duck, greater/lesser scaup, goldeneye, bufflehead, red-breasted mergansers, Canada geese and other seaduck species showed Canada geese and black duck to be the most plentiful species around Great Bay (Vogel, 1995). The 1995 counts for most species were higher than the average count for the previous ten years. Recent counts for waterfowl by the Audubon Society in the Hampton Harbor area are presented in Table 3.9.

Great Bay is a focus area for the North American Waterfowl Management Plan (Vogel, 1995). There are two wildlife preserves in the Great Bay area. One is located in Newington at the site of the old Pease Air Force Base. It consists of a 1,054 acre area bordering Little Bay which has been designated as a Wildlife Sanctuary by the U.S. Fish and Wildlife Service. The other preserve is located at Adams Point and is administered by the NH Fish and Game Department as a Wildlife Management Area. In addition, the Great Bay Estuarine Research Reserve has over 5,300 acres of protected areas that include wetlands,



S. MIRICK

Piping plover chick

TABLE 3.9	*Summary of mid-winter survey and volunteer counts of waterfowl in Hampton Harbor: 1995. Data from Vogel (1995).*

Species		**1995 Counts**	**10 Year Average (1985-1994)**	**Change from 10 Year Averages**	**1995 Volunteer Count Averages**
Mallard	*Anas platyrhynchos*	511	288	77%	493
Black duck	*Anas rubripes*	1,846	973	90%	267
Greater/lesser scaup	*Aythya marila/affinis*	550	360	53%	114
Goldeneye	*Bucephala clangula*	200	79	153%	50
Bufflehead	*Bucephala albeola*	0	5	—	43
Seaduck species		513	436	18%	0
R.B. merganser	*Mergus serrator*	7	8	–13%	26
Canada goose	*Branta canadensis*	3,110	1,603	94%	1,821
Total		6,796	4,200	62%	—

Volunteer data based on the average counts of 6 surveys conducted January-March, 1995 at certain sites around Great Bay. Other species noted during the volunteer survey include domestic geese, mute swans, hooded mergansers, common mergansers, northern pintails, ruddy ducks, and ring-necked ducks.

saltmarshes, uplands and habitat for waterfowl. Other conservation areas include Audubon's Bellamy River property, Nature Conservancy land on Durham Point and other NH Fish and Game areas.

A detailed study of shorebird use of the Great Bay Estuary during the fall and spring migratory periods was conducted in 1990-91 (Miller and Miller, 1991). Data on the relative abundance of 16 shorebird species during a one year period were reported along with habitats used, locations, human influences, management options and research needs. There is a checklist for the birds of Great Bay that lists >170 species by season and abundance (GBNERR, 1993).

3.4.3 NON-GAME SPECIES

A summary of the amphibians, reptiles, mammals and wetland-associated birds in New Hampshire is included as a series of appendices in Chase et al. (1995). The appendices cover terrestrial and semi-terrestrial vertebrates with a few example descriptions of habitat use, survival needs and conservation issues. In New Hampshire there are 39 species of amphibians and reptiles, 55 native mammalian species and over 200 bird species, 51 of which they list as wetland-dependent or wetland-associated. Bald eagles, common terns, upland sand pipers, marsh hawks, ospreys and common loons are endangered and threatened bird species found in the Great Bay Estuary (Merrill, 1995). The bald eagle inhabits the shores of Little and Great Bay in the winter (NH Audubon Society, annual monitoring data).

A study consisting of weekly bird observations made for 12 months during 1980-81 throughout the GBE identified over 90,000 consisting of 71 species (Nelson, 1982). The birds were classified into four categories: seabirds, waterfowl, wading birds and terrestrial and shorebirds. Some species left the area during cold months and were replaced to some extent by other species. The total species in the estuary each month was fairly constant at ~20, ranging from 13 in January to 34 in August.

Great Bay is part of the Atlantic flyway and an important migratory stopover as well as wintering area for many waterfowl and wading birds. As a result, there are both substantial seasonal and year round populations of waterfowl throughout the Great Bay area. Common species include cormorants, Canada geese, bald eagles, sea gulls, terns, ducks, herons, snowy egrets, common loons and a large variety of perching birds.

Wildlife is well represented within the Little Harbor area, primarily at Odiorne State Park, and in the extensive salt marshes of Seavey Creek and Berry

Brook, part of which is owned and managed by Odiorne State Park. Habitat areas in Little Harbor have been mapped. Mammals living in the Little Harbor area include whitetail deer, beaver, fox, mink, otter, muskrat, squirrels, chipmunks, rabbits, moles, voles, rats, mice, bats, shrews, weasels, skunks and raccoons (Seacoast Science Center, 1992). Wildlife populations are not suspected to be large enough to impact water quality, especially considering that most of the shoreline is developed. In addition, the Little Harbor area is a seasonal stopover for many waterfowl and wading birds. Species seen or heard during one or more seasons include common loon, grebes, cormorants, bittern, brant, Canada geese, mallard, eider, oldsquaw, scoters, common goldeneye, bufflehead, mergansers, hawks, kestrel, plovers, killdeer, yellowlegs, willet, sandpipers, godwits, turnstone, dunlin, snipe, gulls, terns, dovekie, owls, whip-poor-will, swift, kingfisher, woodpeckers, flicker, flycatchers, phoebe, kingbird, swallows, jays, crows, chickadee, nuthatches, wrens, kinglets, wheatear thrushes, robin, catbird, mockingbird, cedar waxwing, starling, vireos, warblers, parula, warblers, redstart, yellowthroat, pine and evening grosbeak, towhee, sparrows blackbird, grackle, orioles, finches, crossbill, goldfinch, and a large variety of less common birds.

3.4.4 RARE AND ENDANGERED SPECIES

There are a number of threatened and endangered species in coastal New Hampshire. There are 23 threatened or endangered plant and animal species in the GBNERR. The shortnose sturgeon is a federal endangered species that probably occurs, although this is unproven (NAI, 1994). Detailed descriptions of the six endangered and threatened birds in the coastal region were given in NHOSP (1992). The bald eagle is federally listed as endangered and it occurs in the Salmon Falls, upper Piscataqua, Oyster, Cocheco and Bellamy rivers plus in Little Bay, Great Bay and tributaries, Portsmouth Harbor and Back Channel area, and in Hampton Harbor and its tributaries. It also probably occurs in the Exeter and Lamprey rivers plus Rye Harbor. The piping plover is federally listed as threatened and occurs in parts of Hampton Harbor and its tributaries. The peregrine falcon, once federally listed as endangered but now delisted, has documented occurrences in the upper Piscataqua River and in Hampton Harbor and its tributaries. A more comprehensive list of threatened or endangered species in the GBNERR is in Appendix L.

Foss and De Luca (1992) assessed the breeding season distribution, habitat use, status and nesting success of four threatened or endangered bird species in coastal New Hampshire. The species included common terns (state endangered), ospreys (state threatened), norther harriers (state threatened) and piping plovers (state endangered; federally threatened). Tern colonies were located in Hampton marsh, Back Channel and Little Bay. Northern harriers used coastal habitats in 1992, but there was no proof of nesting. Piping plover habitat exists on the southeast shore of Hampton Harbor, but no breeding was observed in 1992. Osprey nests in four locations were monitored and some breeding activity was observed. The report included monitoring and management recommendations for each species. Others have continued monitoring the four existing osprey nests around Great Bay (C. Martin, NH Audubon Society, personal communication).

In 1997, the NHOSP funded a project by the NH Audubon Society and the NHF&G Department Nongame Program to restore terns to the Isles of Shoals (NHF&G, 1997a). Seven chicks hatched from six nests, and efforts will be made to repeat this success next year. The NHF&G Nongame Program also protected and monitored five piping plover nests at Seabrook and Hampton beaches in 1997. Three of the seventeen chicks survived and fledged in August. The others either starved or were run over by vehicles or joggers. This was the first documentation of nesting piping plovers in New Hampshire since 1984.

INTRODUCED AND NUISANCE SPECIES

The objective of this section is to synthesize current information on selected species relevant to shellfish and other living resources, not necessarily to be a comprehensive review of all introduced and nuisance species.

3.5.1 GREEN CRABS *(Carcinus maenas)*

Introduced and Nuisance

Green crabs were introduced into North America in the early 1900's and have been identified as a major predator of juvenile shellfish. In the Great Bay Estuary, green crabs are more abundant in the Piscataqua River and Little Bay than in Great Bay. Though there is some information on crab density at eelgrass mitigation sites in the Piscataqua River, the data are insufficient to establish the status and trends of green crab populations in Great Bay. Normandeau Associates Inc. has monitored green crab populations in Hampton Harbor since 1977 using baited traps (NAI, 1996). Their data show that crab density in a given year is highly dependent on the minimum winter temperature, and that colder temperatures result in fewer crabs the following spring (Savage and Dunlop, 1983). Survival of clam spat appears to be negatively correlated with crab density (NAI, 1996). Green crabs as well as rock crabs (*Cancer irroratus*) and mud crabs (all of which are abundant in Great Bay) also prey on juvenile oysters. Green crabs have been identified as serious pests that threaten efforts to restore eelgrass beds in the Great Bay Estuary. Descriptive study and mesocosm experiments have shown that their foraging and burrowing activities kill and dislodge planted shoots (Davis et al., in review).

Green crab

S. MILLER

3.5.2 EUROPEAN OYSTER *(Ostrea edulis)*

Introduced

Discussed in another section.

3.5.3 COMMON PERIWINKLE *(Littorina littorea)*

Introduced

This introduced species is highly abundant in coastal and estuarine waters. As a grazer, it is primarily herbivorous, but will scavenge on detritus as well. Through its foraging activities, the common periwinkle has a significant role in estuarine food webs, and influences (and may control) community patterns along rocky shorelines (Mathieson et al., 1991). However, the widespread distribution of this 19th century colonizer has left ecologists with little opportunity to collect evidence and test whether *Littorina littorea* has caused adverse impacts on coastal and estuarine ecosystems in the Gulf of Maine.

3.5.4 OYSTER DRILL *(Urosalpinx cinerea)*

Nuisance

The oyster drill, a predatory gastropod, preys heavily on oysters in higher salinity waters. Intolerant of low salinities, drills typically cannot survive extended periods in areas of Great Bay where major oyster beds are located, although they have been found at Nannie Island and Adams Point. During extended high salinity periods, they can cause significant mortalities. The status and trends of drill populations, and their impact on oyster population has not been documented.

3.5.5 SEA LETTUCE *(Ulva lactuca)*

Nuisance

Proliferation of ephemeral green algae such as *Ulva latuca* due to nutrient overenrichment has caused serious ecosystem alterations in many areas of the world (Sawyer, 1965). Though severe impacts have not been documented in the Great Bay Estuary, anecdotal observations of increased abundance of *Ulva latuca* and other opportunistic green algae should prompt some analysis of the change in areal coverage and biomass of these so called "nuisance" macrophytic algae. A project that addresses this subject began in 1997 and is described in section 2.4.5.3.

3.5.6 OTHER INTRODUCED AND NUISANCE PLANTS

The major nuisance species associated with declines in seagrass habitats worldwide are various species of algae, including opportunistic red and green species that form mats and drift into beds, epiphytic species that cover individual blades, and phytoplankton that can shade entire beds (Short and Wylie-Echeverria, 1996). Although epiphytes and drift algae are known to occur in seagrass beds in New Hampshire's estuaries, impacts to eelgrass beds do not appear to be significant at this time (Short et al., 1993; Langan and Jones, 1993). However, experimental model ecosystems of eelgrass beds indicate that nutrient additions can lead to algal dominance and seagrass bed collapse (Short et al., 1995).

In New Hampshire, Widgeon grass (*Ruppia maritima*) occurs primarily in creeks, ponds, and pannes of salt marshes (Richardson, 1980). However, it also occurs extensively in South Mill Pond, Portsmouth, where it must compete with various species of opportunistic macroalgae. What little is known about habitat change regarding the macroalgal beds of New Hampshire estuaries includes studies on the destruction of estuarine and near shore populations of kelp by a small species of estuarine snail, *Lacuna vincta* (Fralick et al., 1974) and previously mentioned increases in macroalgal habitat by *Ulva latuca* and other opportunistic species.

Several species of emergent plants are considered nuisances in tidal marshes. These include common reed (*Phragmites australis*, formerly *communis*), purple loosestrife (*Lythrum salicaria*), and sometimes cattail (*Typha angustifolia*) (USDA, 1994).These plants drastically reduce plant diversity in marshes, restrict bird and fish access to the marsh, and have been cited as a fire hazard to nearby homes (USDA, 1994; Rozsa, 1995). The presence and spread of these species can serve not only as indicators of impacts to marshes (USDA, 1994), but as indicators of losses in marsh functions and values (Morgan et al., 1996). Thus, these invasive plants are believed to reduce the economic value of salt marshes (USDA 1994). All three species are clearly increasing in coastal marshes (Dzierzeski, 1991; USDA, 1994; Tiner, 1996). Phragmites is cited as the "most significant problem confronting" salt marshes in Connecticut (Rozsa, 1995), and its continued spread and establishment in New Hampshire marshes is cause for concern. Management action plans have been developed and implemented to curb this problem. For example, where these plants have invaded tidally-restricted marshes, reestablishment of natural tidal regimes have reduced their distribution or vigor (Burdick and Dionne, 1994; Burdick et al., 1997).

Within salt marshes, human nuisances such as mosquitos and greenhead flies are managed by seacoast towns that collectively spend approximately $100,000 each year. Ironically, most of the effort to control these pests occur in marshes that have degraded, often as a result of efforts to manage such pests (USDA 1994).

3.6

SUMMARY OF FINDINGS

The review of technical information on the status and trends for living resources in coastal New Hampshire showed a great deal of existing information for a wide range of different species and communities. There are issues that emerge from analysis of the data for some species, while little is known about others. This section is a summary of what is known and what information gaps still exist.

- The species richness and dominant species found in communities of benthic invertebrates in the Great Bay Estuary were essentially unchanged from 1972 to 1995.
- A few benthic invertebrate and macroalgae species are disjunct warm-water taxa, with their northernmost contiguous distribution limit occurring south of New Hampshire.
- Eastern oysters are found mainly in the Great Bay Estuary in coastal New Hampshire.
- Eastern oyster populations in the Great Bay Estuary have undergone a marked decline during the past half century.
- The first recorded MSX epizootic in the Great Bay Estuary occurred in 1995. There was a high rate of mortality in the upper Piscataqua River and tidal Salmon Falls River, and a lower rate of systemic infections in the rest of the Estuary.
- The causative agent of Dermo disease in oysters, *Perkinsus marinus*,was identified in oysters from Spinney Creek in September, 1996. A low prevalence of Dermo infections have also been found in oysters from Great Bay and the Oyster River.
- European flat oysters, razor clams, ribbed mussels, the gem clam and rock, green, mud and horseshoe crabs are found in numerous areas of coastal New Hampshire.
- Softshell clams are found in high densities in Hampton Harbor and in moderate to high density in flats in the Salmon Falls River and near Sandy Point in Great Bay. Clams are present at low densities in Little Bay, Great Bay and Little Harbor.
- In the Great Bay Estuary and Little Harbor, clam populations are a fraction of their historical levels.
- In Hampton Harbor, clam populations were abundant in the mid-1970s and 1980s, with a sharp decline starting in 1984, likely due to heavy harvest pressure. The decline was also a result of sarcomatous neoplasia, a form of leukemia in clams.
- Blue mussels are found in all New Hampshire's estuaries and open coast, except in the upper reaches of tributaries where low salinity limits their survival. Their abundance has not been documented, and their density can be as high as 3500/m2 in Hampton Harbor.
- Sea scallops can be found in Portsmouth Harbor with an average density of 1.3 scallops/m2 and an even distribution of sizes.
- Lobster populations are relatively stable throughout coastal New Hampshire, despite increasing fishing pressure.

- A tremendous increase in the seasonal occurrence of striped bass has occurred in New Hampshire in the past decade, probably as a result of an earlier region-wide moratorium and other harvest restrictions.
- The recreational catch per unit effort of winter flounder has declined in Great Bay over the last decade, probably as a result of heavy commercial fishing in the Gulf of Maine.
- The abundance of rainbow smelt and river herring has been highly variable over the last decade.
- New Hampshire has approximately 50% of its 18th century tidal wetlands, or about 7,500 acres. Plants found in these areas include cord, spike and black grasses.
- Marine and terrestrial development pose the greatest current threat to salt marshes.
- Tidal restrictions are relatively widespread, affecting 21% of the salt marsh area in New Hampshire.
- There are 219 known species of seaweeds found along the rocky shorelines and the subtidal photic zones of areas throughout coastal New Hampshire. Dredging and development pose threats to macroalgal habitats.
- Eelgrass habitat is a significant component of the Great Bay Estuary ecosystem. Distribution maps, some over time, have been compiled for many areas of coastal New Hampshire.
- Eelgrass populations experience dramatic temporal and spatial changes. A dramatic decline occurred in the late 1980s in Great Bay at a rate of 230 ha/y, followed by a rapid recovery after 1989, at a rate of 600 ha/y. The decline was a result of a wasting disease.
- Harbor seals, harbor porpoises are commonly found, especially in lower Great Bay Estuary, Rye Harbor and Hampton Harbor. An occasional other marine mammal such as humpback whales has also been seen.
- The Seacoast area is the principal wintering location for waterfowl in New Hampshire, 75% of which are in Great Bay. Counts of most species made in Hampton Harbor during 1995 were higher than the average from the previous ten years.
- There are 23 threatened or endangered animal and plant species in the Great Bay National Estuarine Reserve. Monitoring and habitat restoration projects are being conducted for bald eagles, ospreys, common terns and piping plovers.
- Introduced and nuisance species of particular concern in coastal New Hampshire include green crabs, European oysters, common periwinkle, oyster drill, sea lettuce, common reed, purple loosestrife, mosquitos and greenhead flies.